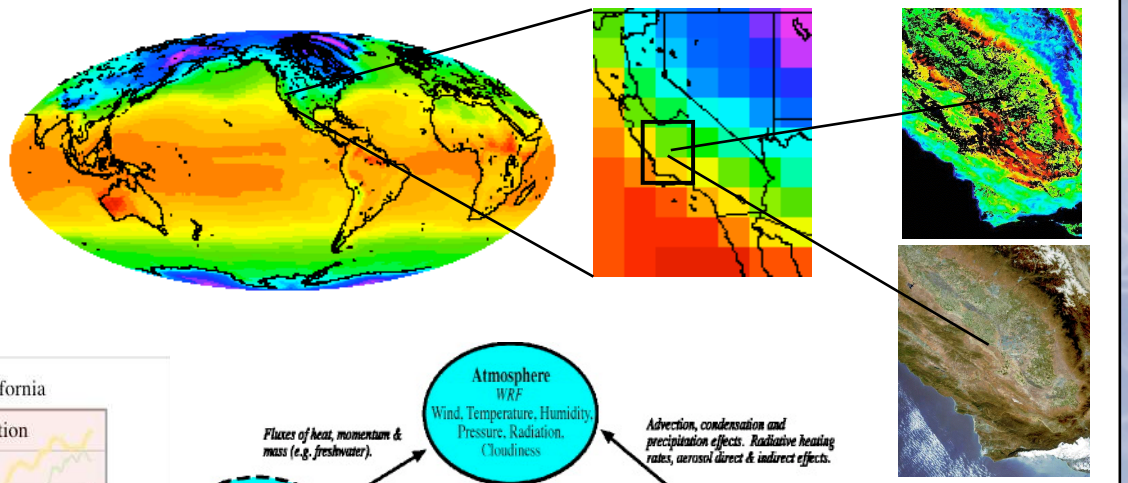
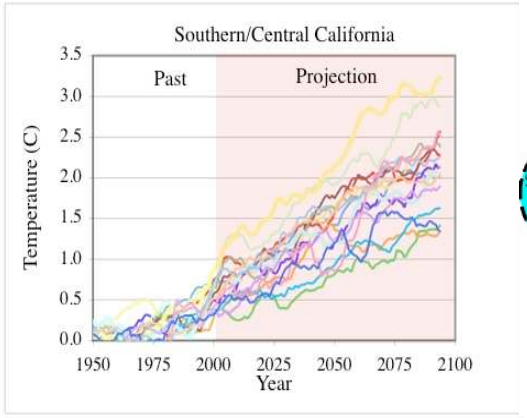
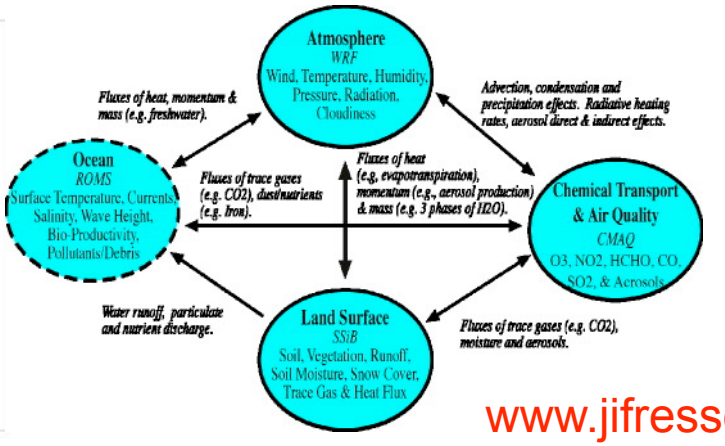
Anthropogenic Climate Changes in California:
Hydroclimate, Snowpack, and Santa Ana Winds

JPL: *Duane Waliser, Yi Chao, Qinbin Li, Annmarie Eldering*
UCLA: *Jinwon Kim, Kuo-Nan Liou, Yongkang Xue, Alex Hall, Mimi Hughes, Sarah Kapnick, Robert Fovell, Jim McWilliams*

5th Annual California Climate Change Conference
Sacramento Convention Center September 8 - 10, 2008







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Outline

- UCLA + JPL Joint Institute
- JIFRESSE Research Foci & Objectives
- Regional Model Development & Framework

Outline

- Today's California Climate Change Themes
  - Hydroclimate *(Kim et al. 2008; POSTER 4)*
  - Sierra snowpack & snow physics *(Kapnick and Hall, 2008; Waliser et al. 2008; POSTERS 54 & 5x?)*
  - Santa Ana wind conditions *(Hughes et al. 2008; POSTER 45)*

Outline

- Summary and Future Work

California Climate Change: UCLA+JPL

In 2006, UCLA & JPL established a Joint Institute for Regional Earth System Science & Engineering (JIFRESSE) to promote, stimulate, and engage UCLA *(Modeling)* and JPL *(Observations)* in cutting edge Earth System science research to:

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California Climate Change: UCLA+JPL

In 2006, UCLA & JPL established a Joint Institute for Regional Earth System Science & Engineering (JIFRESSE) to promote, stimulate, and engage UCLA *(Modeling)* and JPL *(Observations)* in cutting edge Earth System science research to:

- Increase understanding about factors that affect climate-related environmental changes, with particular attention to regional/CA issues;
- Support the design of future JPL/NASA space missions & observation networks related to detecting, monitoring, and projecting climate changes;
- Enhance the educational mission of UCLA through collaboration with JPL.

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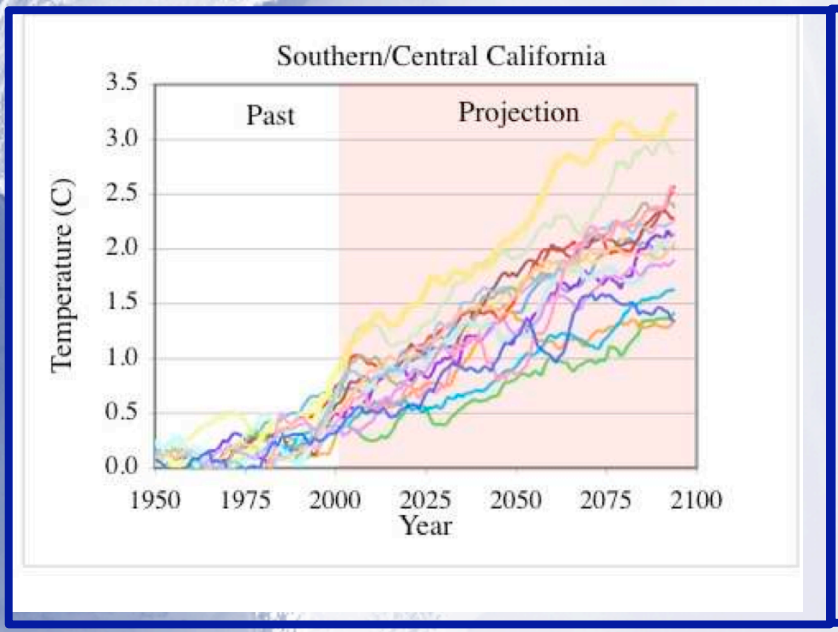
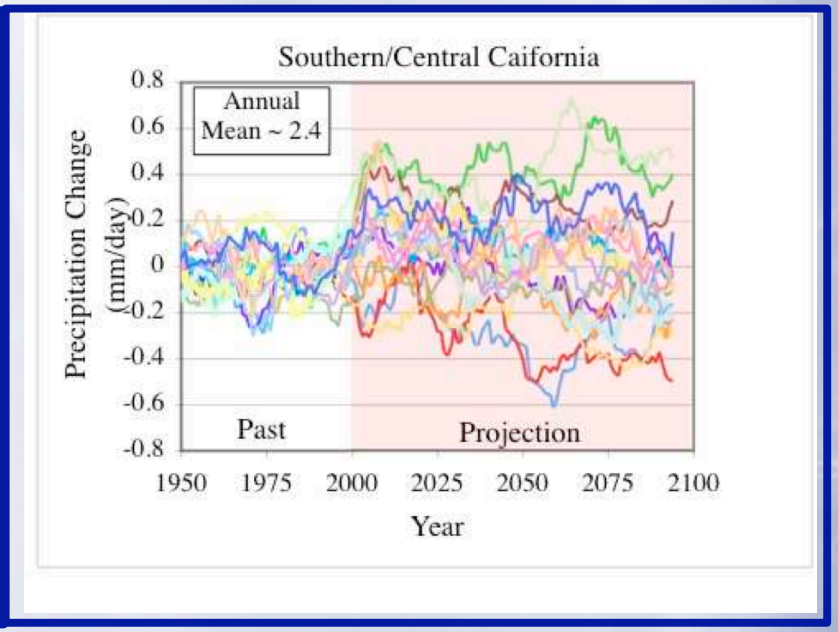
California Climate Change: Motivation

IPCC AR4 model projections agree that California will warm in this century but disagree on whether it will become wetter/drier. This implies that some physical processes are inadequately represented in GCMs.

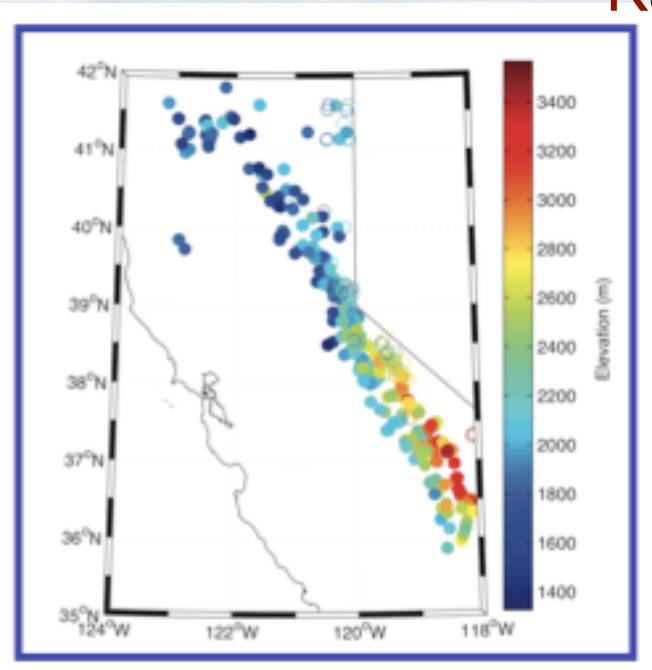




Apply our unique strengths in system engineering and observations (JPL) and process understanding and modeling (ULCA) to improve our capabilities to detect and predict changes in California's climate and ecosystems and contribute to the State's awareness and understanding, and adaptation and mitigation strategies.

California Snowpack Change: Motivational Study

Kapnick & Hall, 2008



- ✓ A snow water equivalent dataset was developed from 1930 -2007.

California Snowpack Change: Motivational Study

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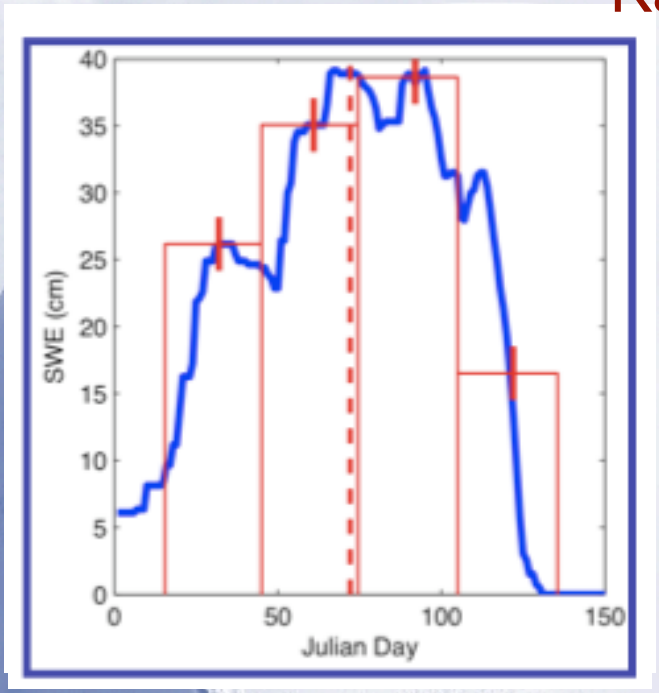

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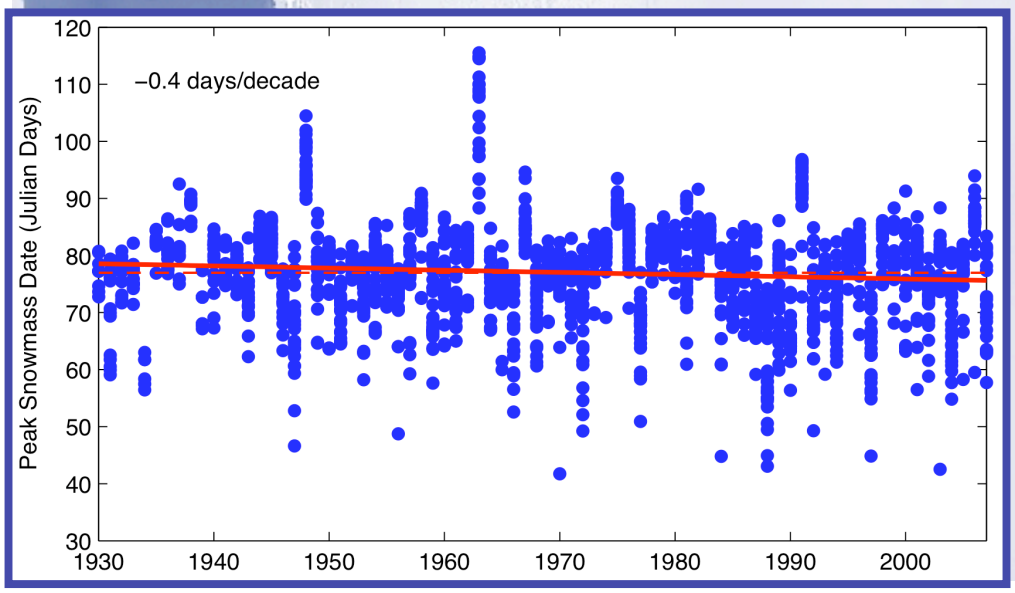

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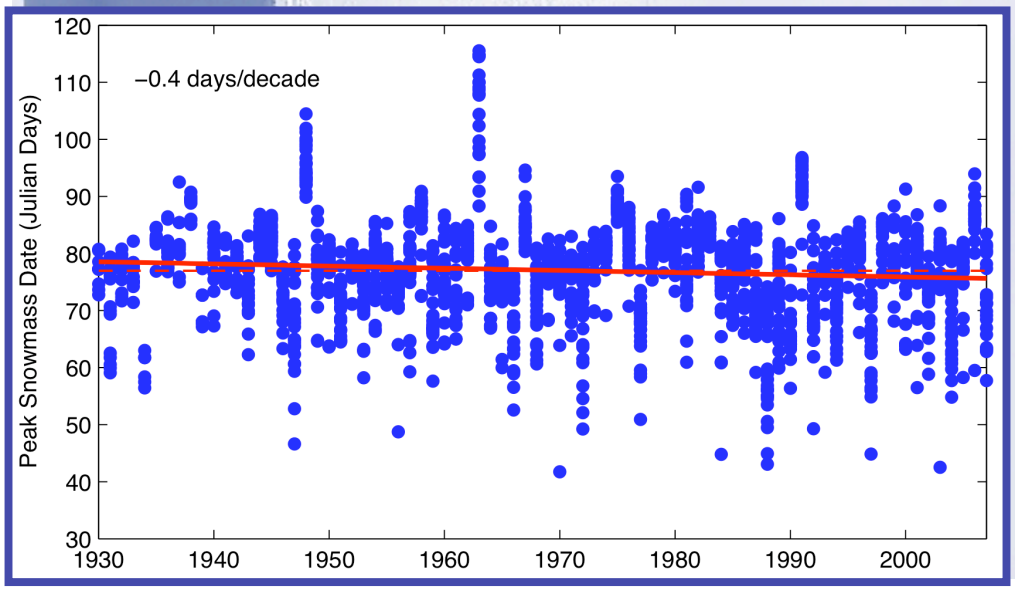
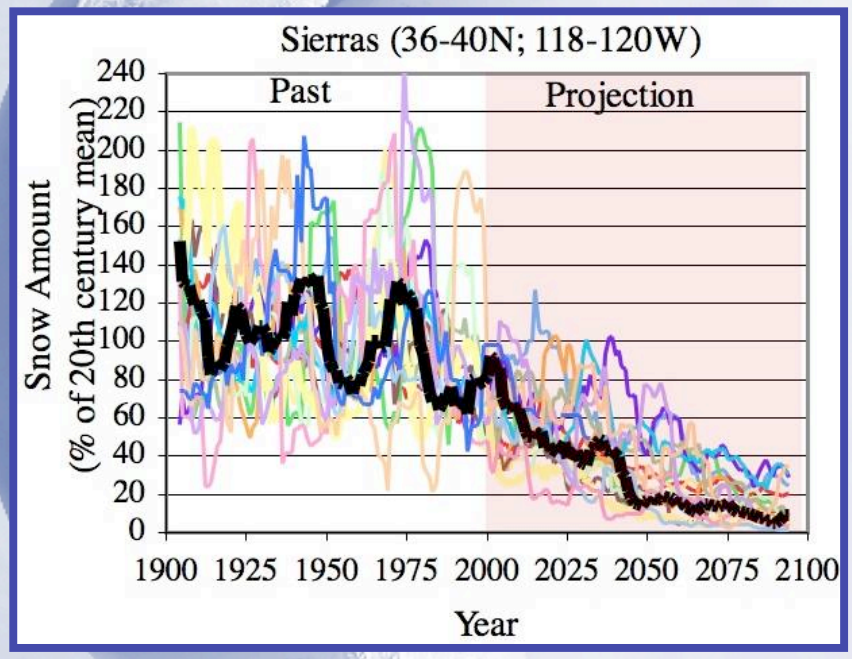


Based on these results and considerations of temperature projections, the date of peak snow mass would be expected to occur 3-9 days earlier by end of century.

California Snowpack Projections: Model Uncertainties

What do the models (directly) project?

IPCC AR4 Projections



But how realistic?

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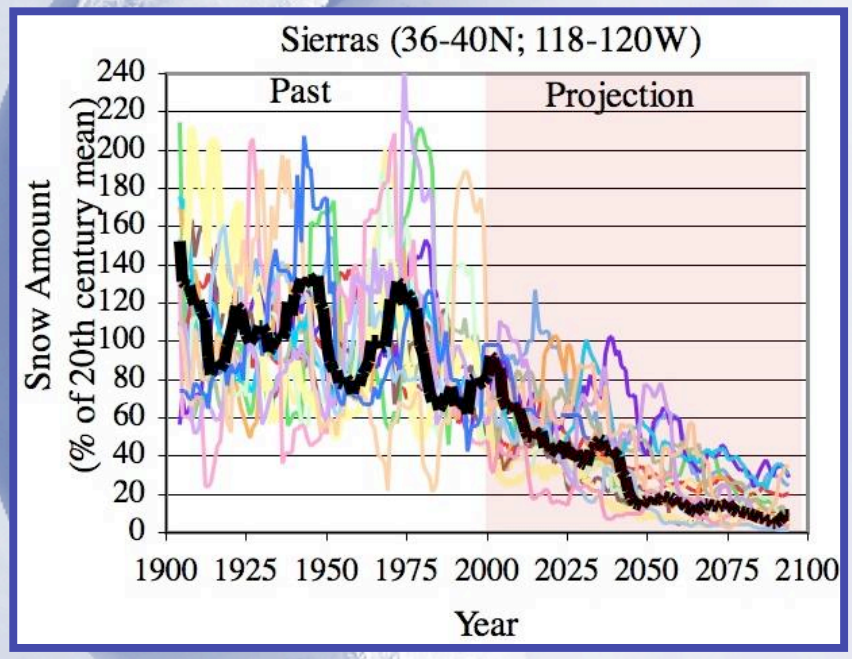

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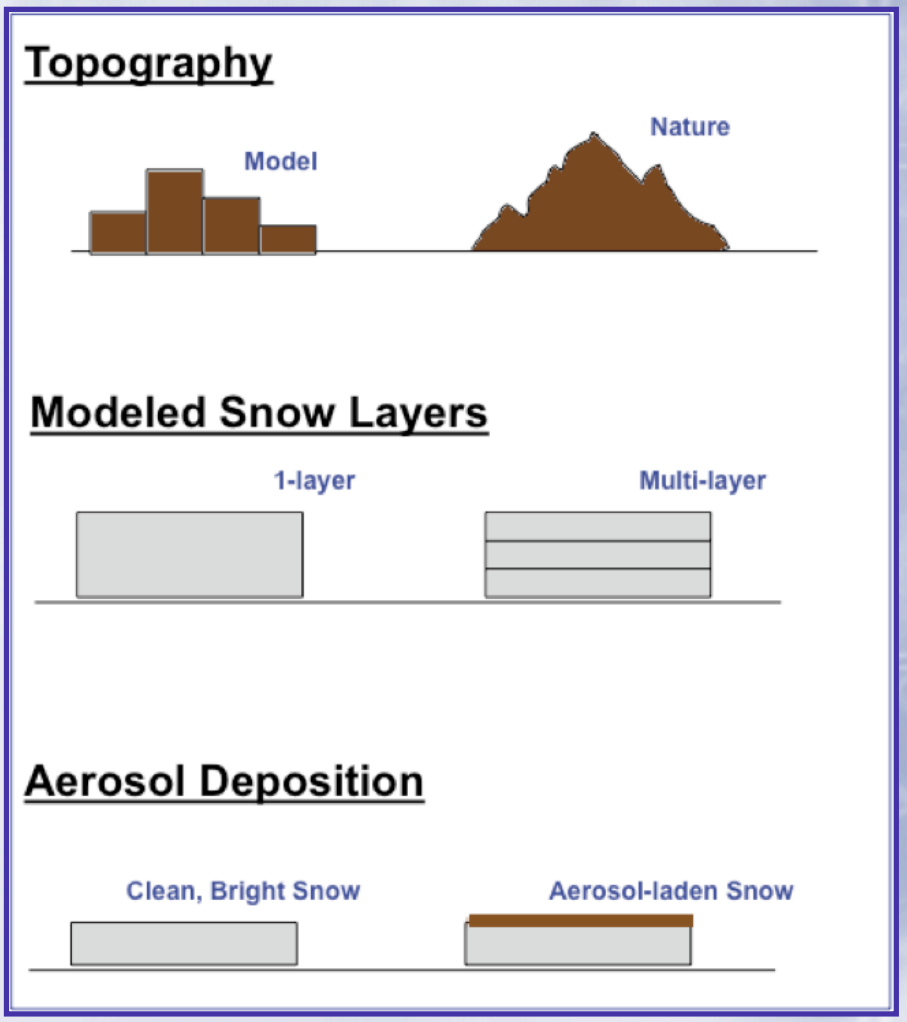

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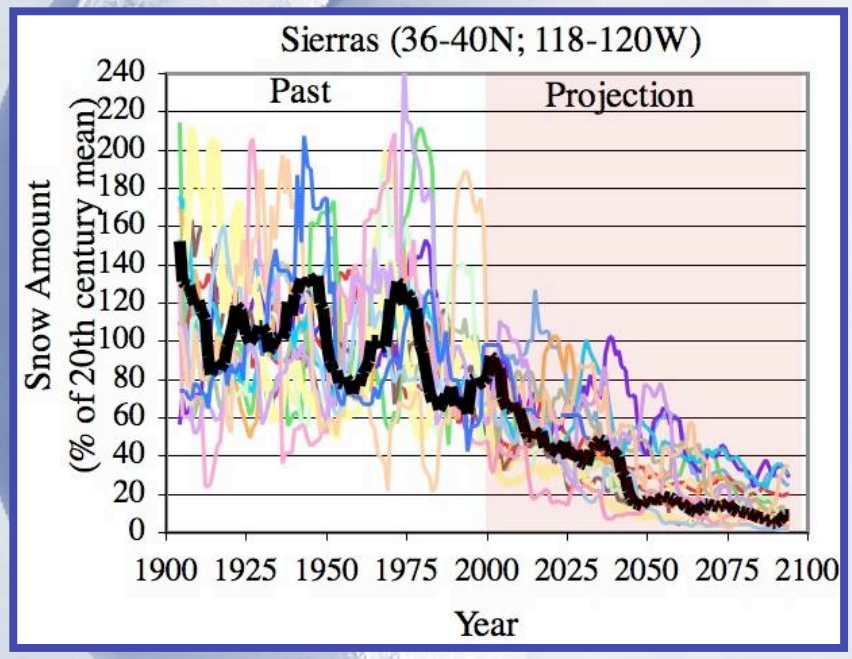

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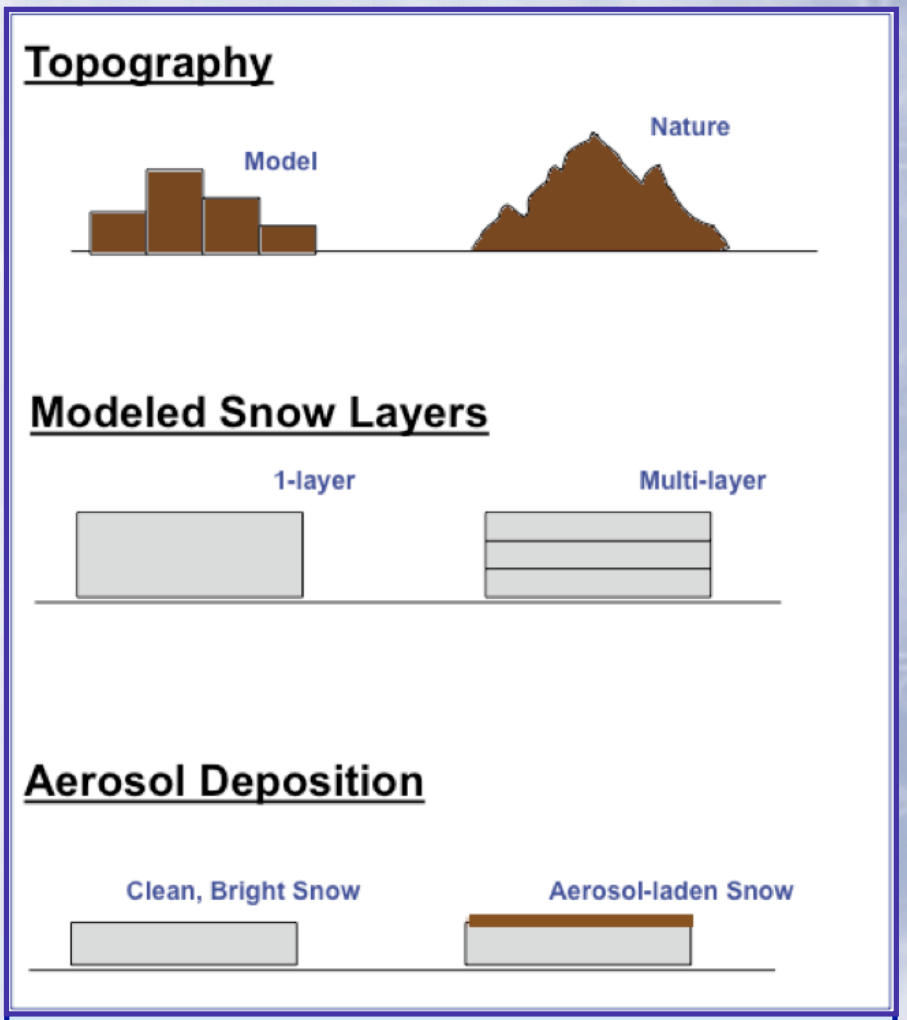

These are the types of questions JIFRESSE is addressing.

JIFRESSE: Building a Regional Earth System Model

RESMs – *and their dynamic downscaling of GCMs* - afford:

- greater spatial resolution [O(1-10km)]
- inclusion of more processes and interactions
- closer connections to societal impacts
- a complementary role to GCMs
- a numerical laboratory for GCM parameterization development

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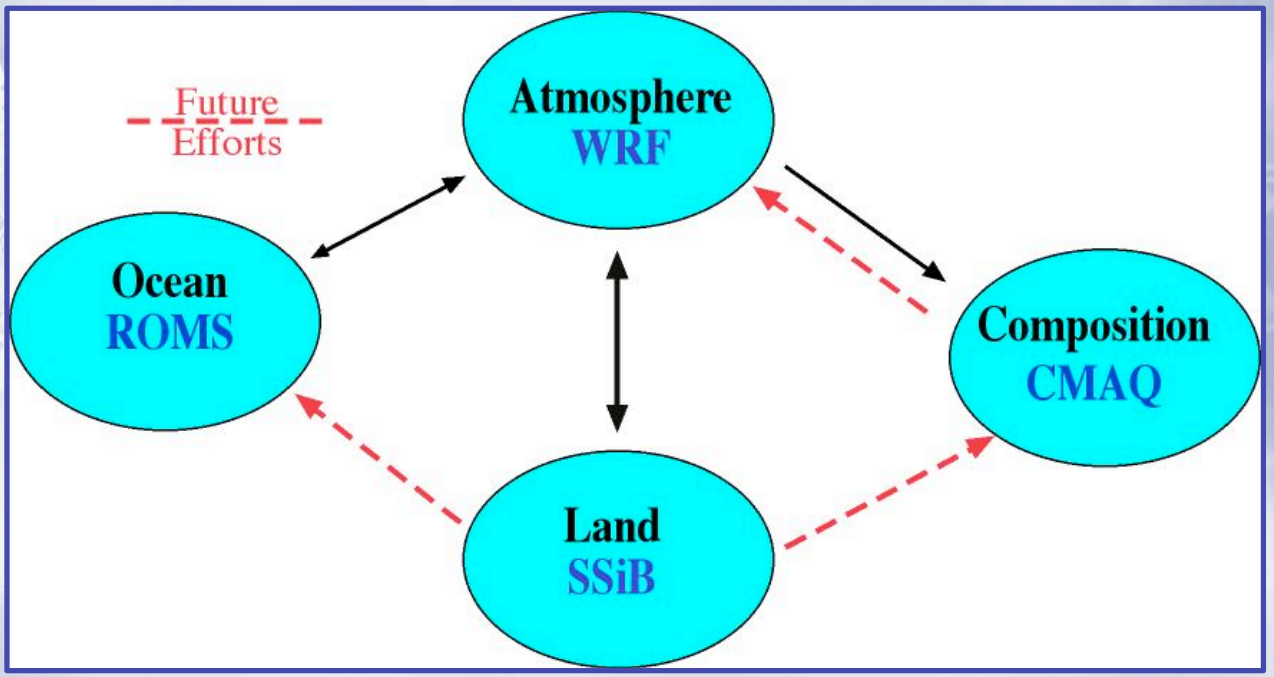
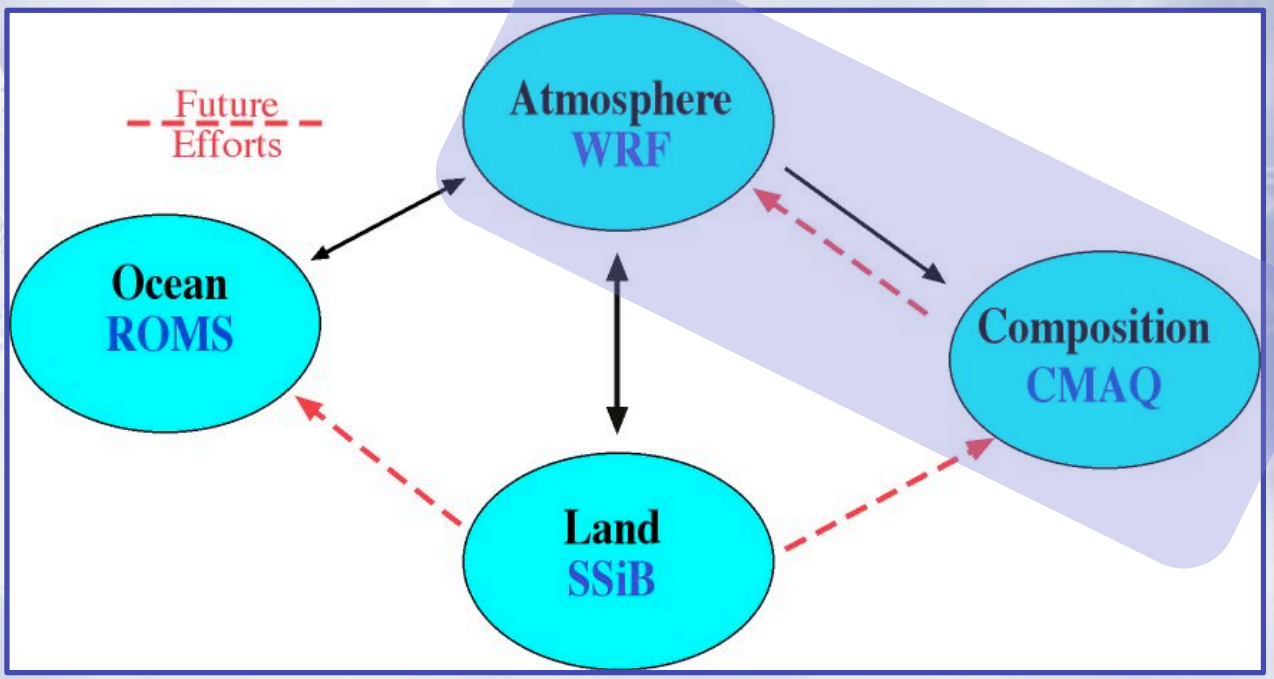
JIFRESSE Regional *Earth System Model*



JIFRESSE: Building a Regional Earth System Model

JIFRESSE Regional *Earth System Model*

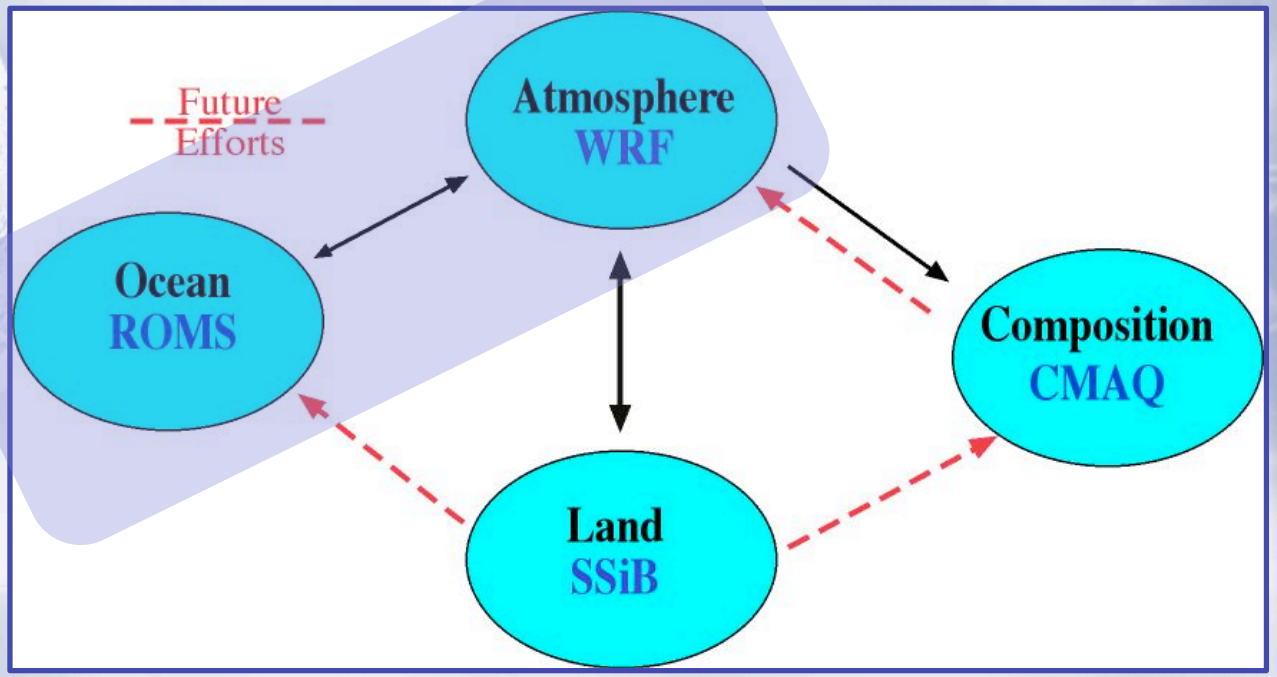
Ongoing & Future Air Quality Studies



JIFRESSE: Building a Regional Earth System Model

Ongoing Atmos-Ocean & Ocean-Bio Coupling Studies & Forecasts

JIFRESSE Regional *Earth System Model*



JIFRESSE: Building a Regional Earth System Model

Ongoing
Hydrology and Synotpic
Studies e.g. Today's Snowpack
& Santa Ana Wind
Studies

JIFRESSE
Regional
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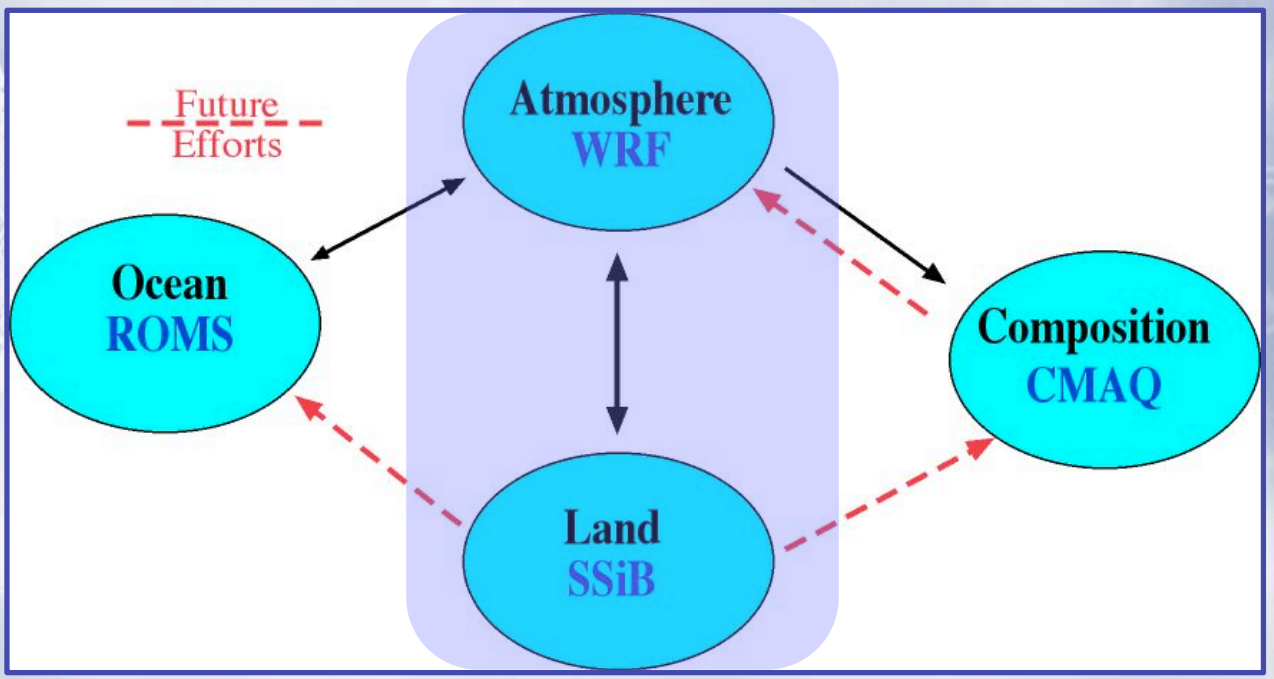

California Climate Change: Dynamical Downscaling

Climate Change Experiments

Forcing

Climate Change Projection
NCAR CCSM3 – SRESA1B Scenario
1971-1980
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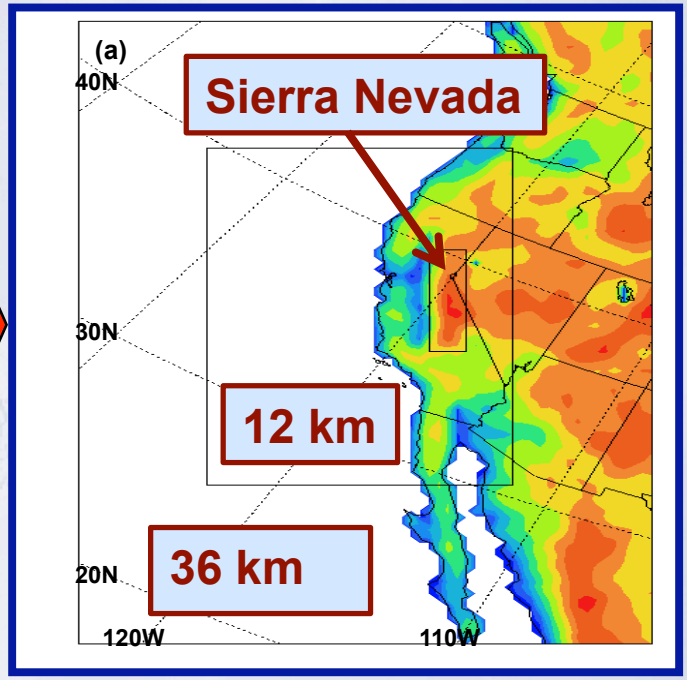

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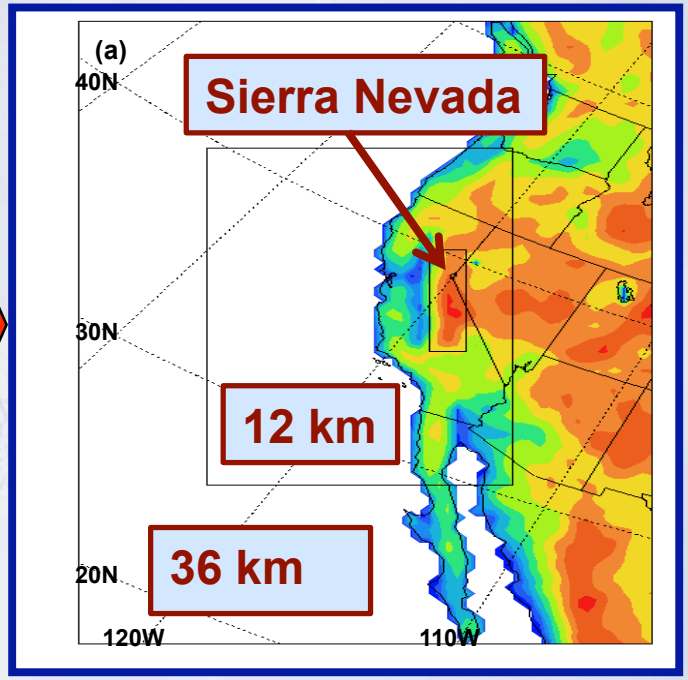
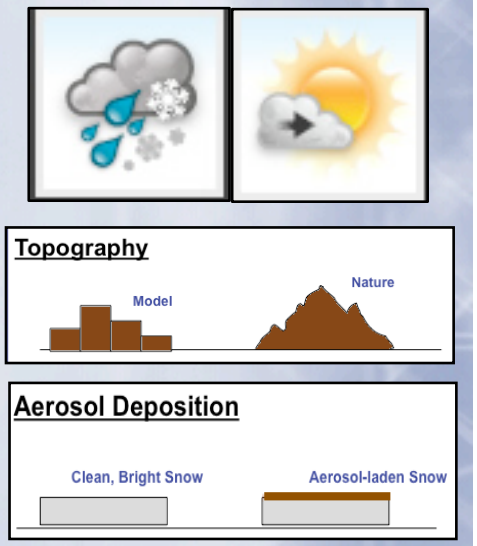
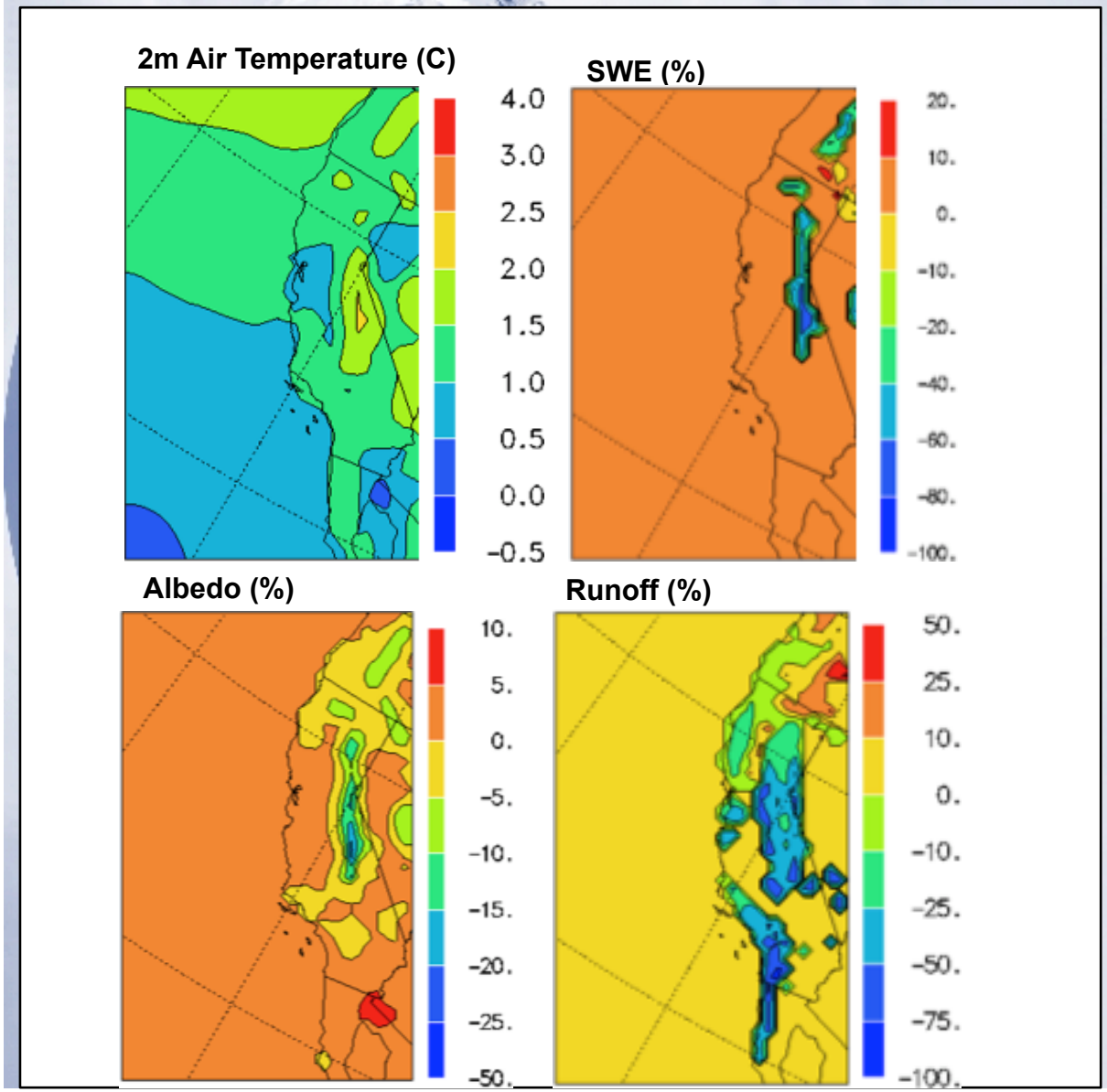


Results



California Climate Change: Dynamical Downscaling

Hydroclimate Changes: Oct-March; ~2050 vs 1975; 36km



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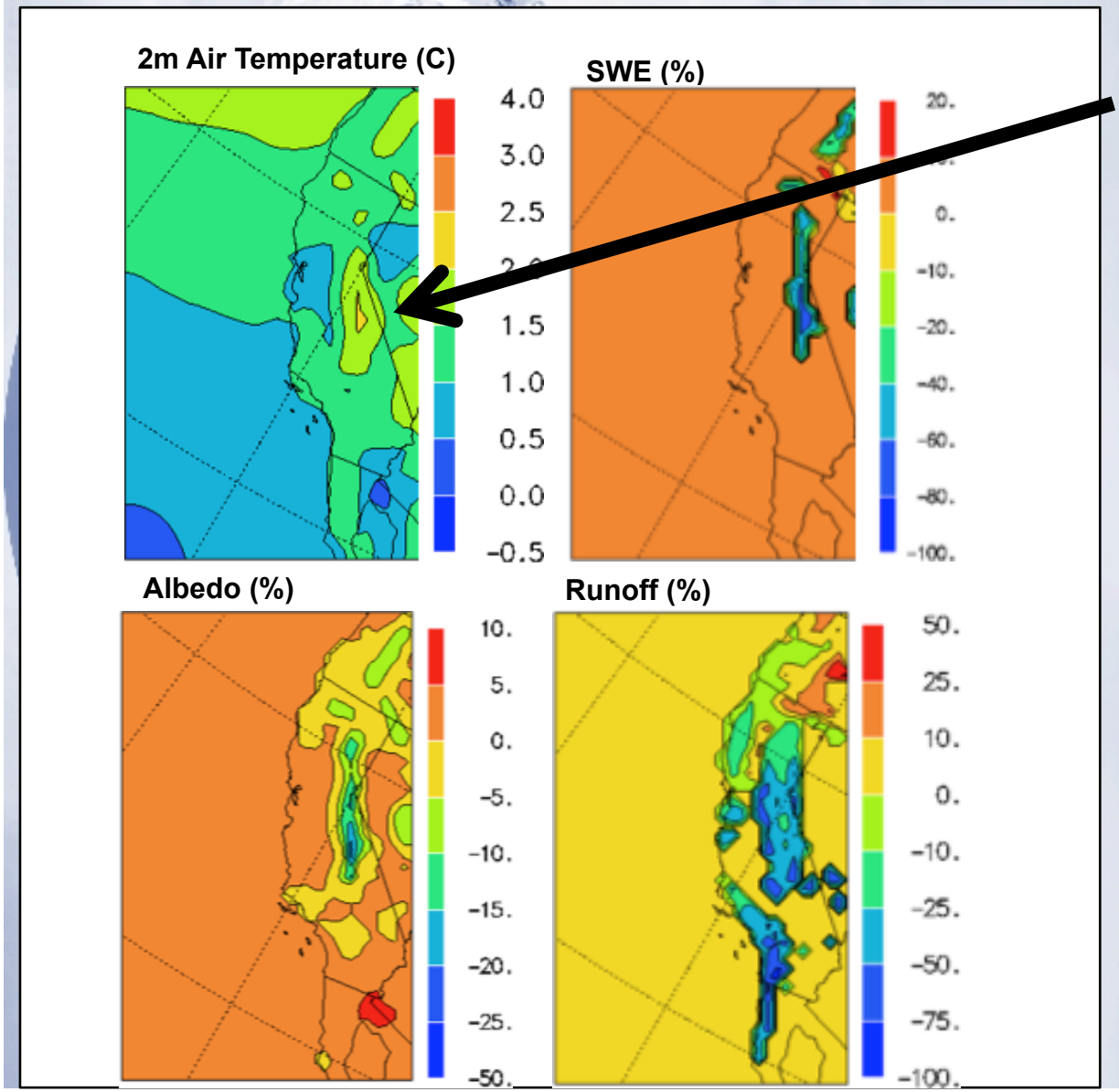

Warming: 0º to 2.5ºC. Larger with altitude.

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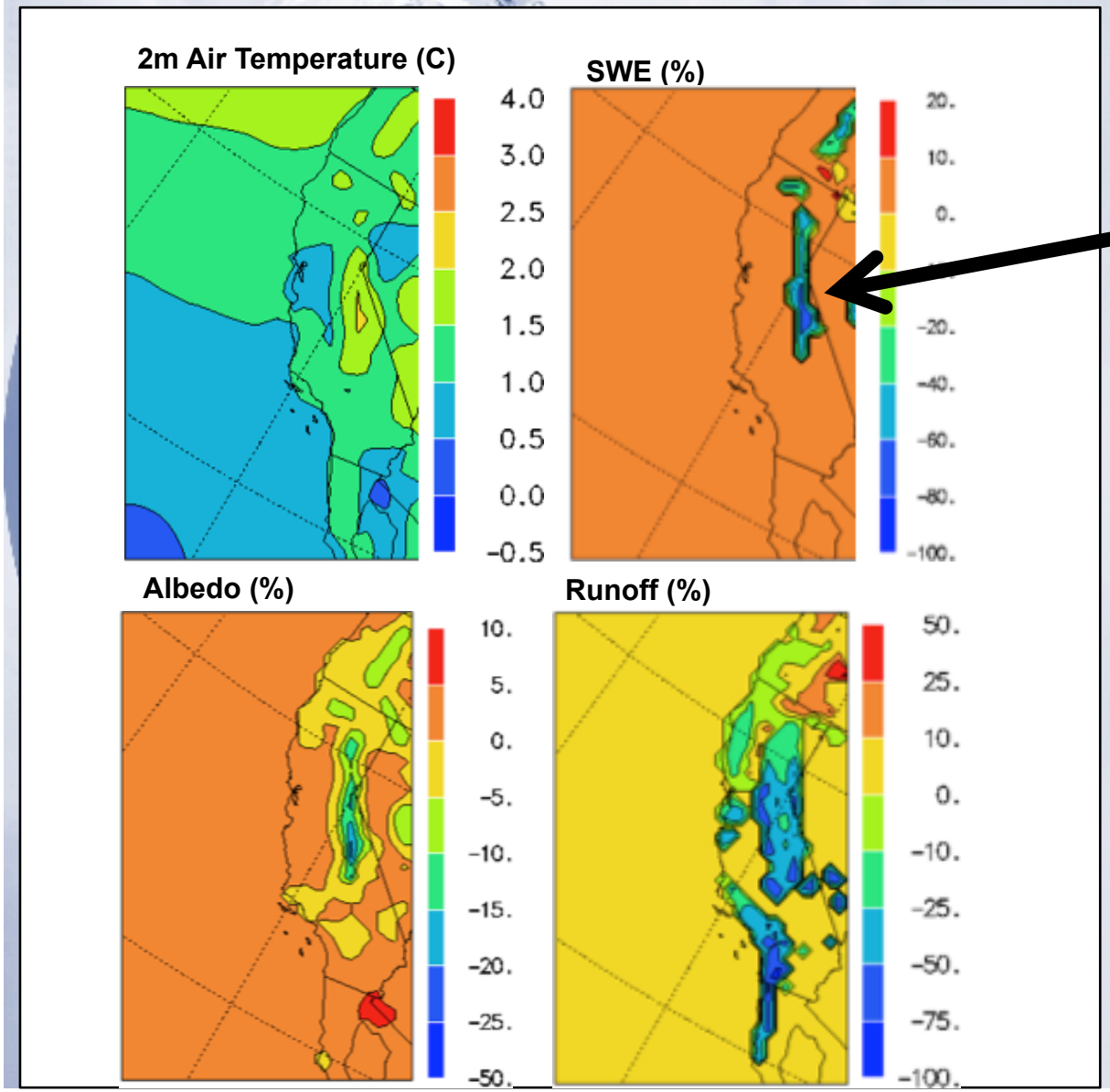

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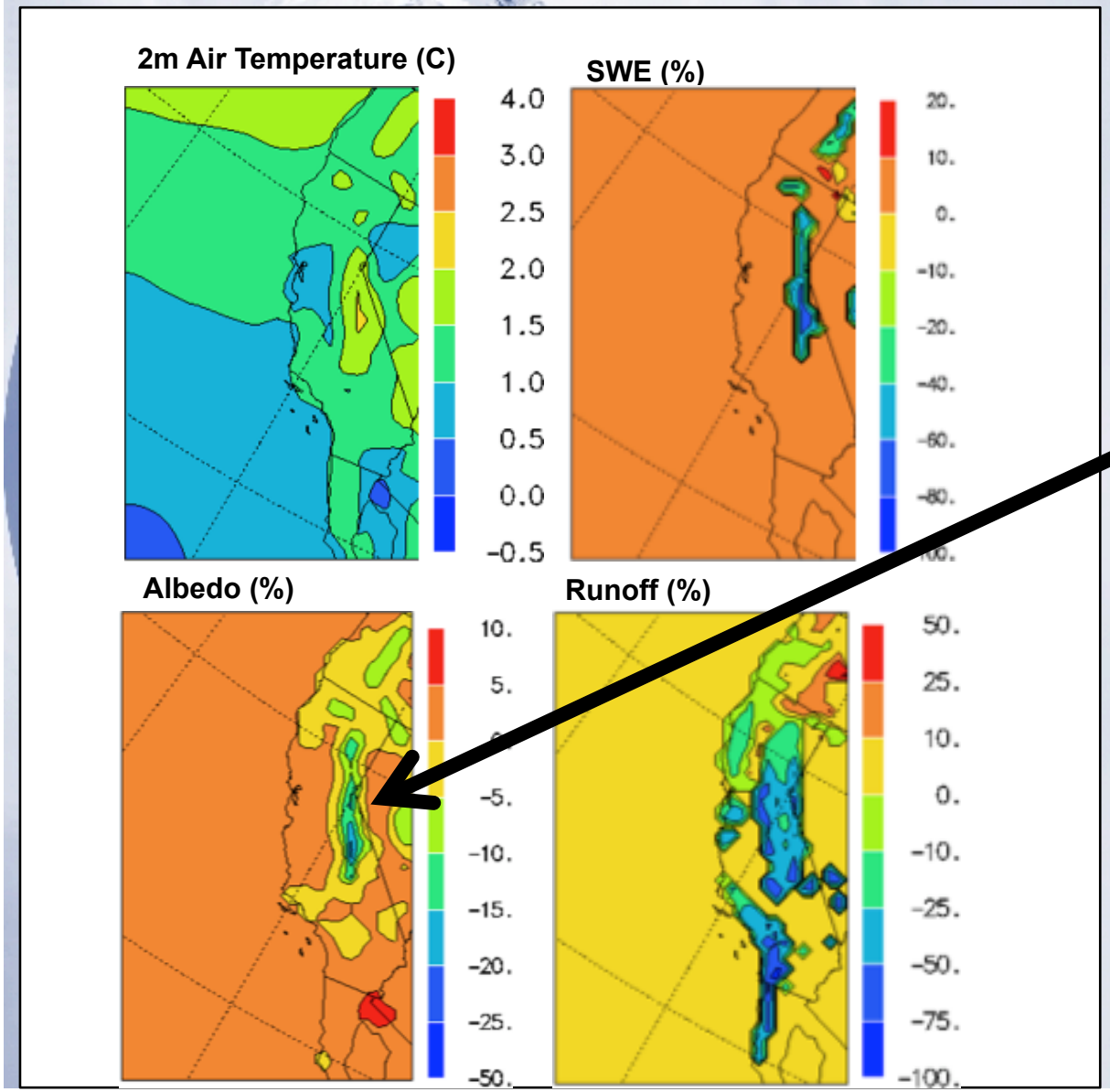

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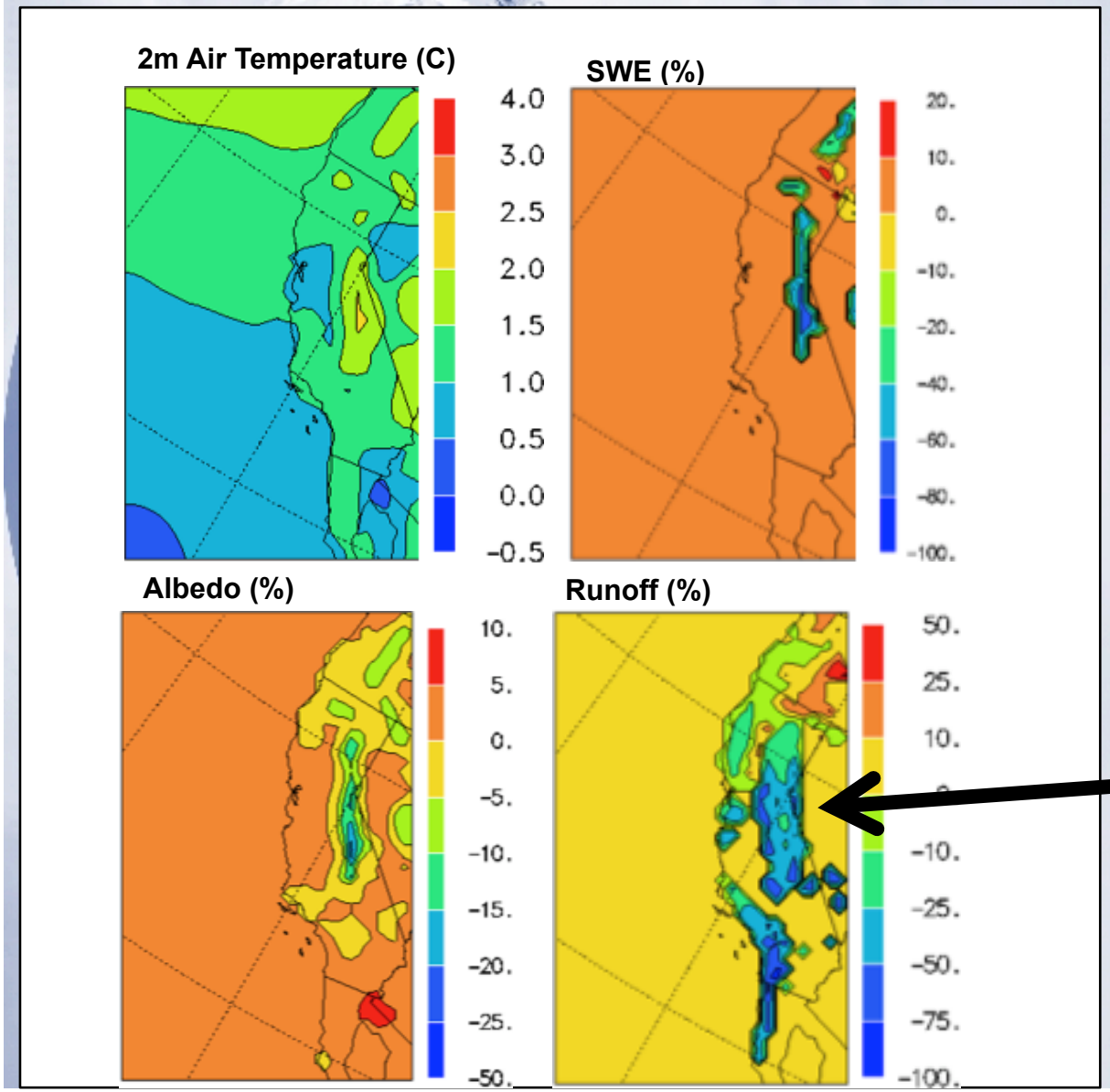

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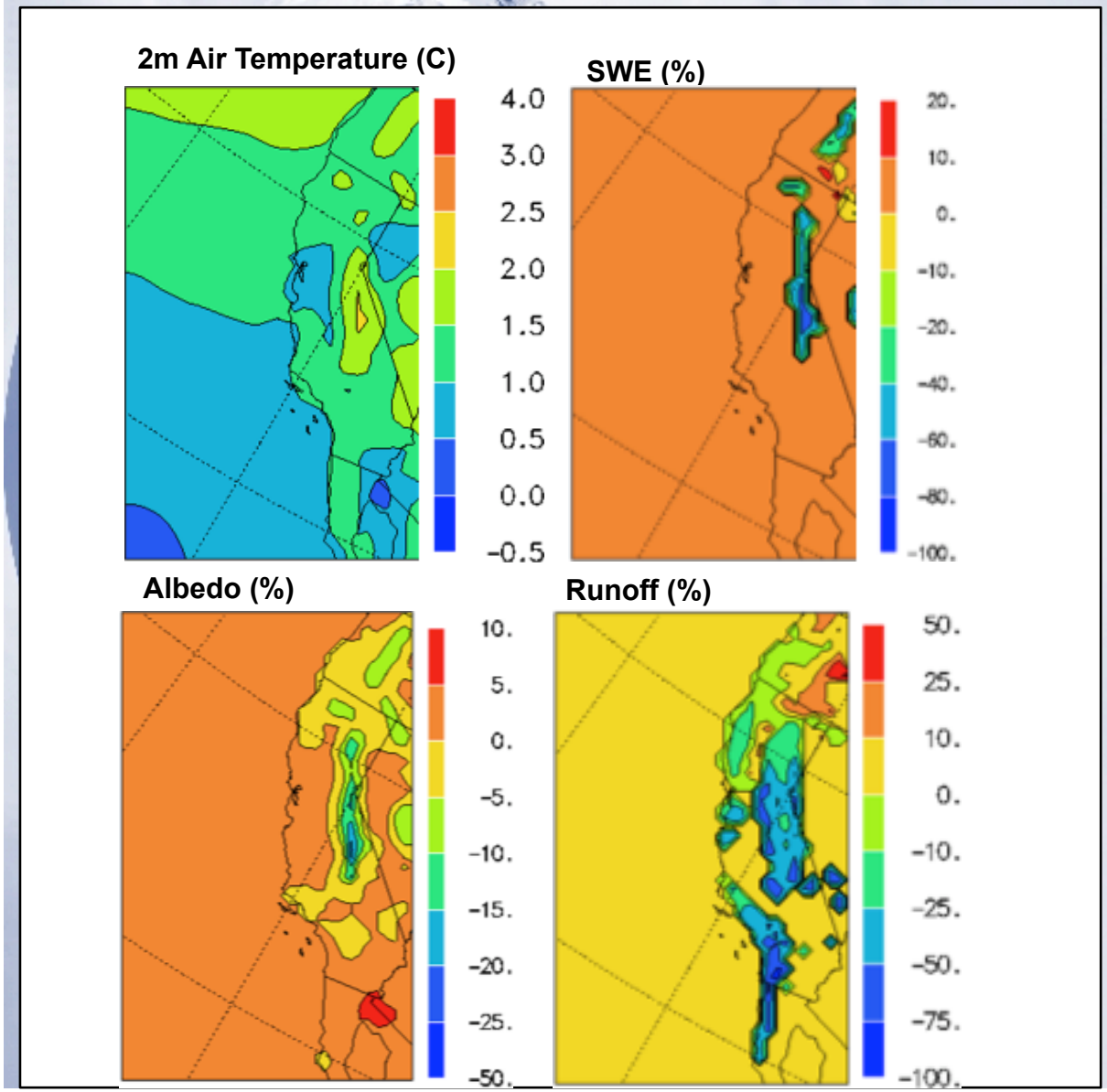

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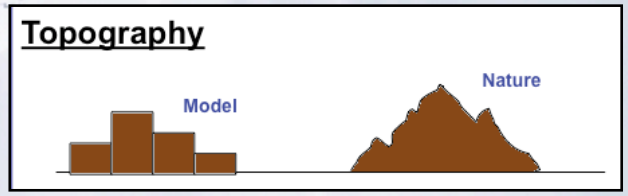
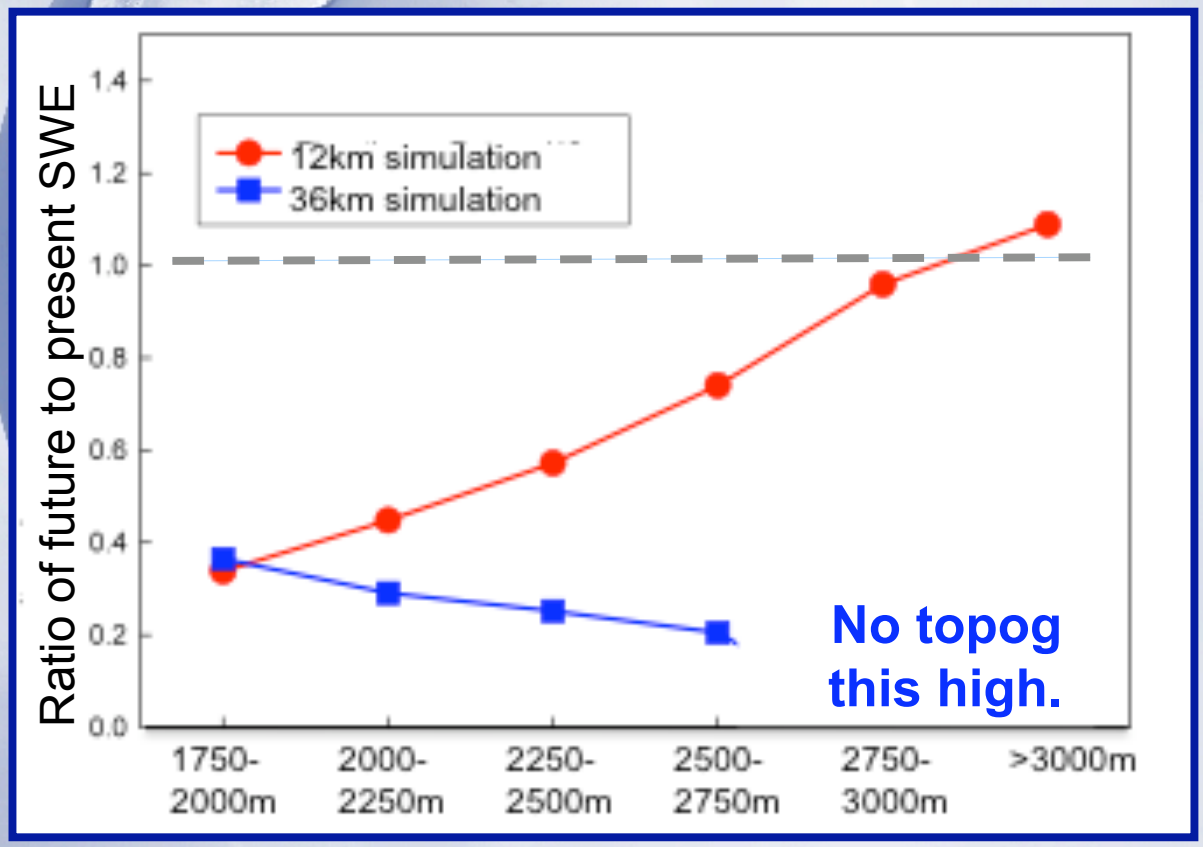
Snow physics modeling is important

California Climate Change: Dynamical Downscaling

Impact of Model Resolution/Topography

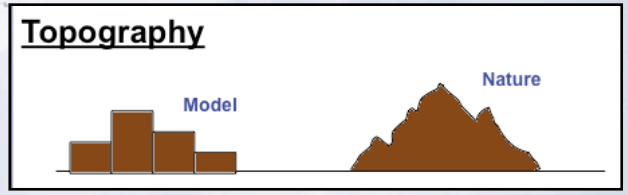


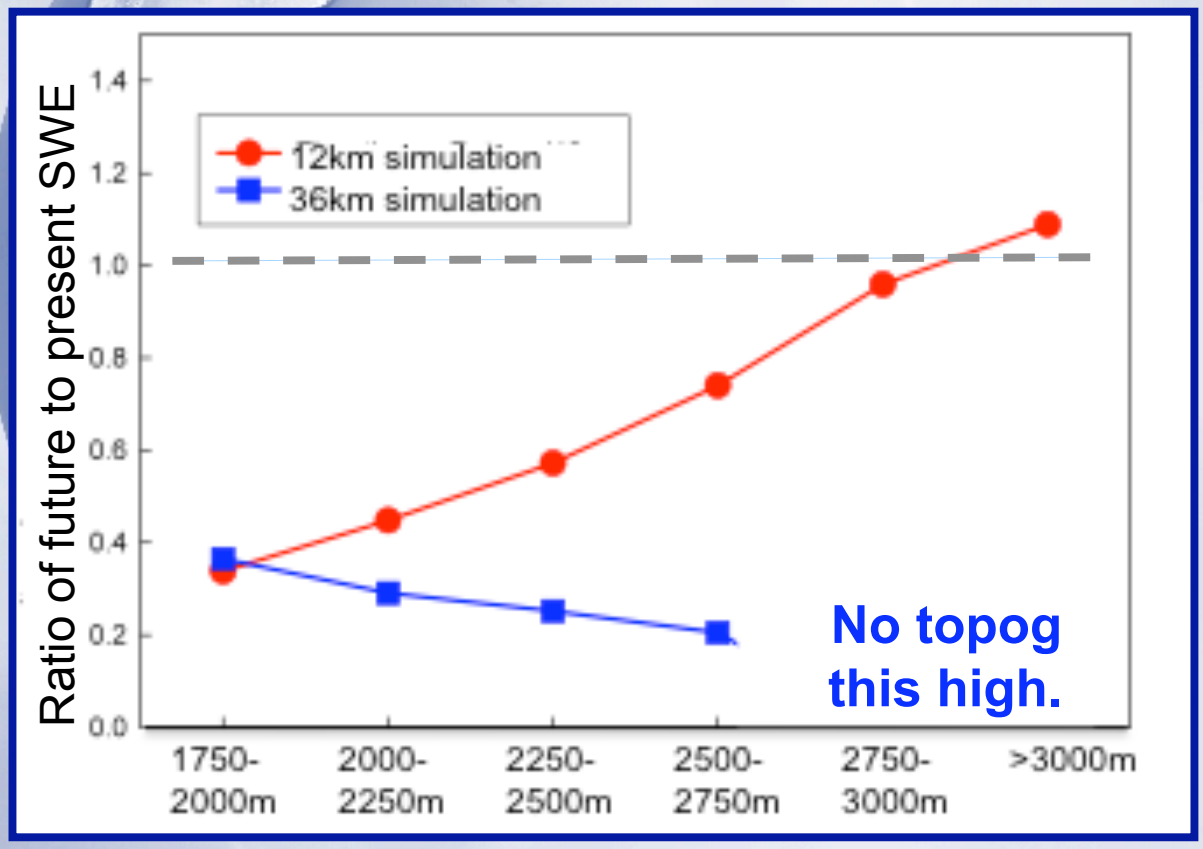


LOW ELEVATION **HIGH ELEVATION**

California Climate Change: Dynamical Downscaling

Impact of Model Resolution/Topography





- SWE is generally less in projected future climate.
- Differences in 12km vs 36km are not due to differences in changes to snowfall.

California Climate Change: Dynamical Downscaling

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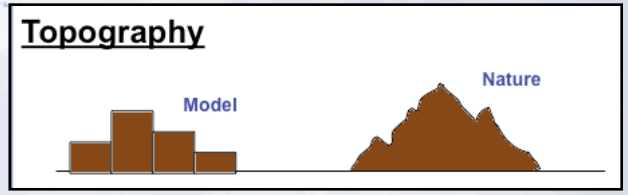
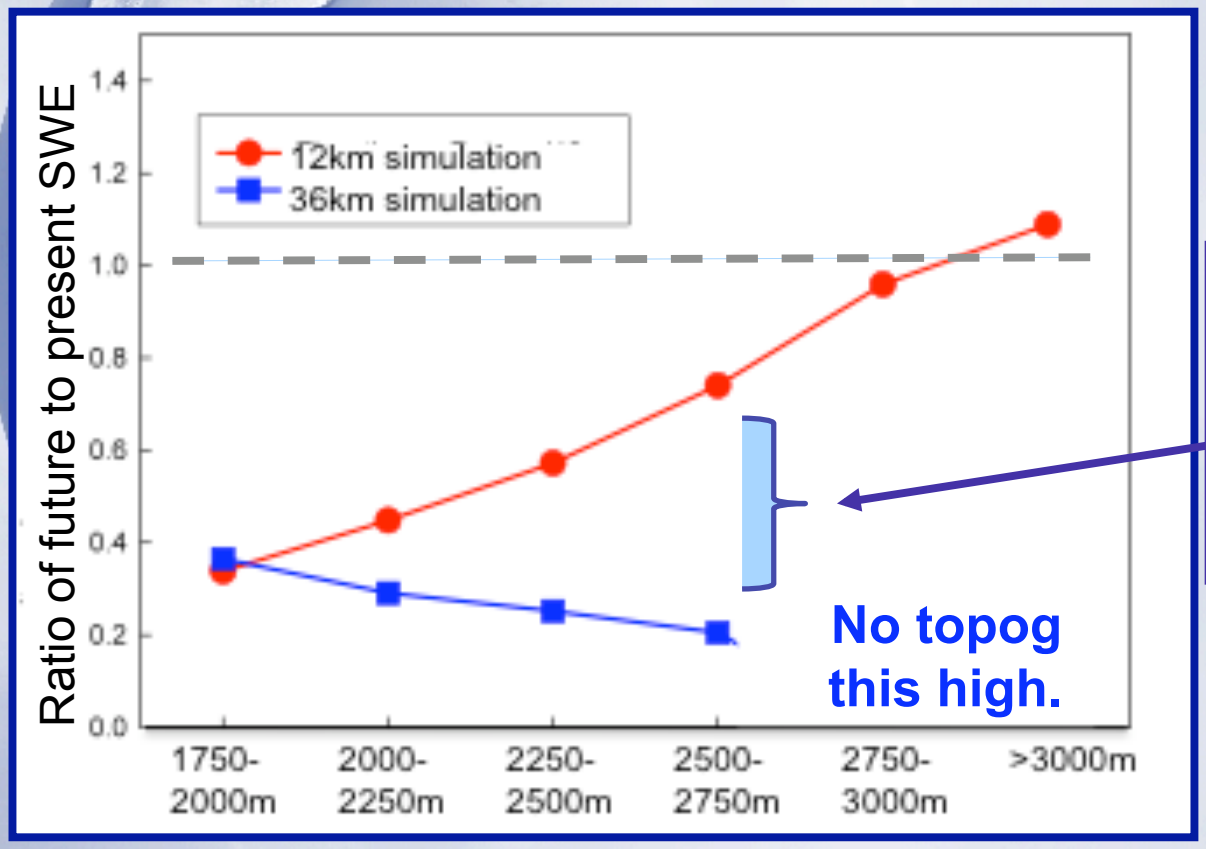
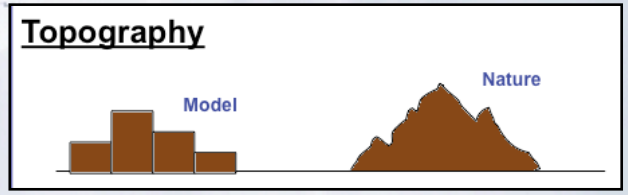


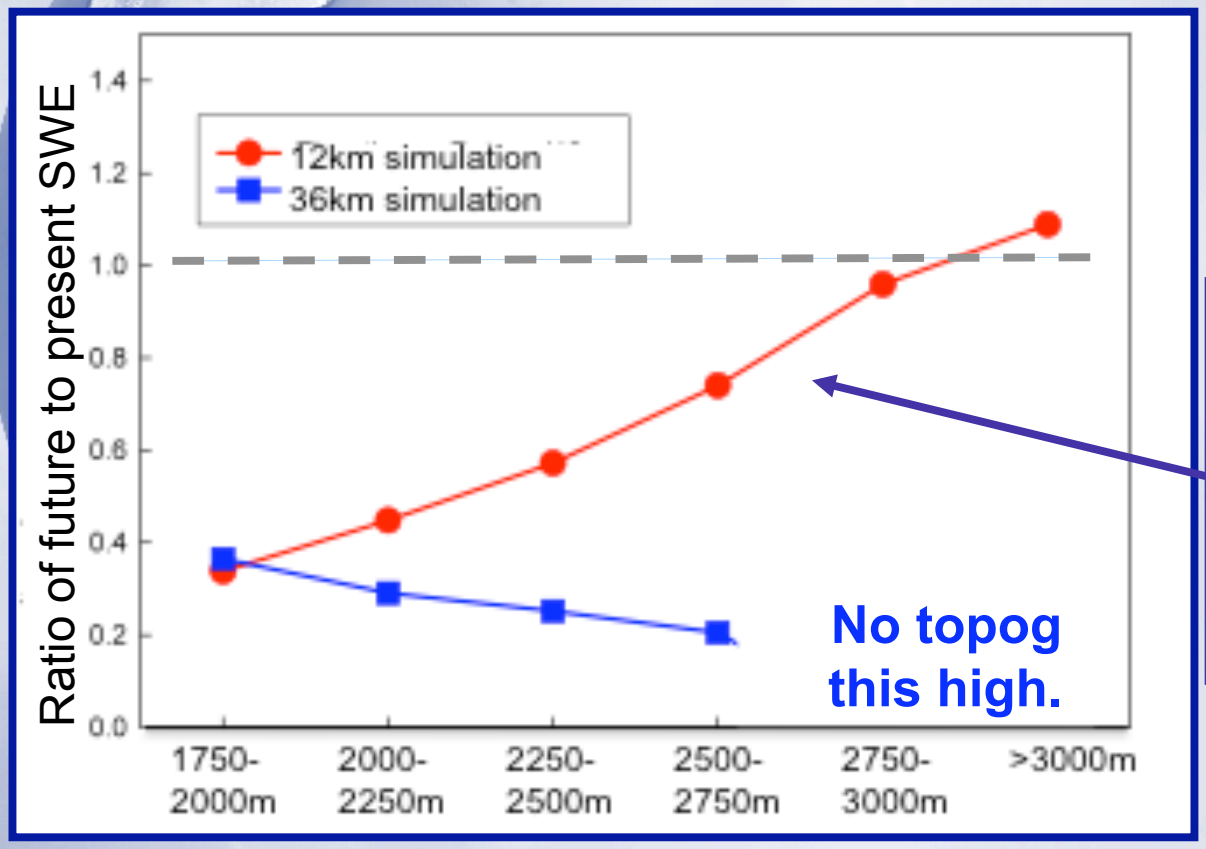


Greater reduction in snowpack in 36km => likely due to greater snow -albedo feedback since overall less snow.

California Climate Change: Dynamical Downscaling

Impact of Model Resolution/Topography





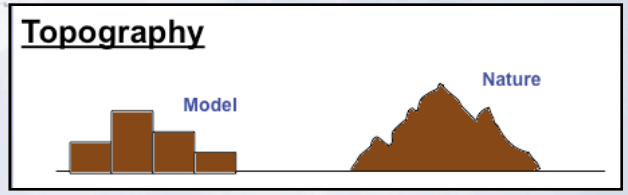
LOW ELEVATION

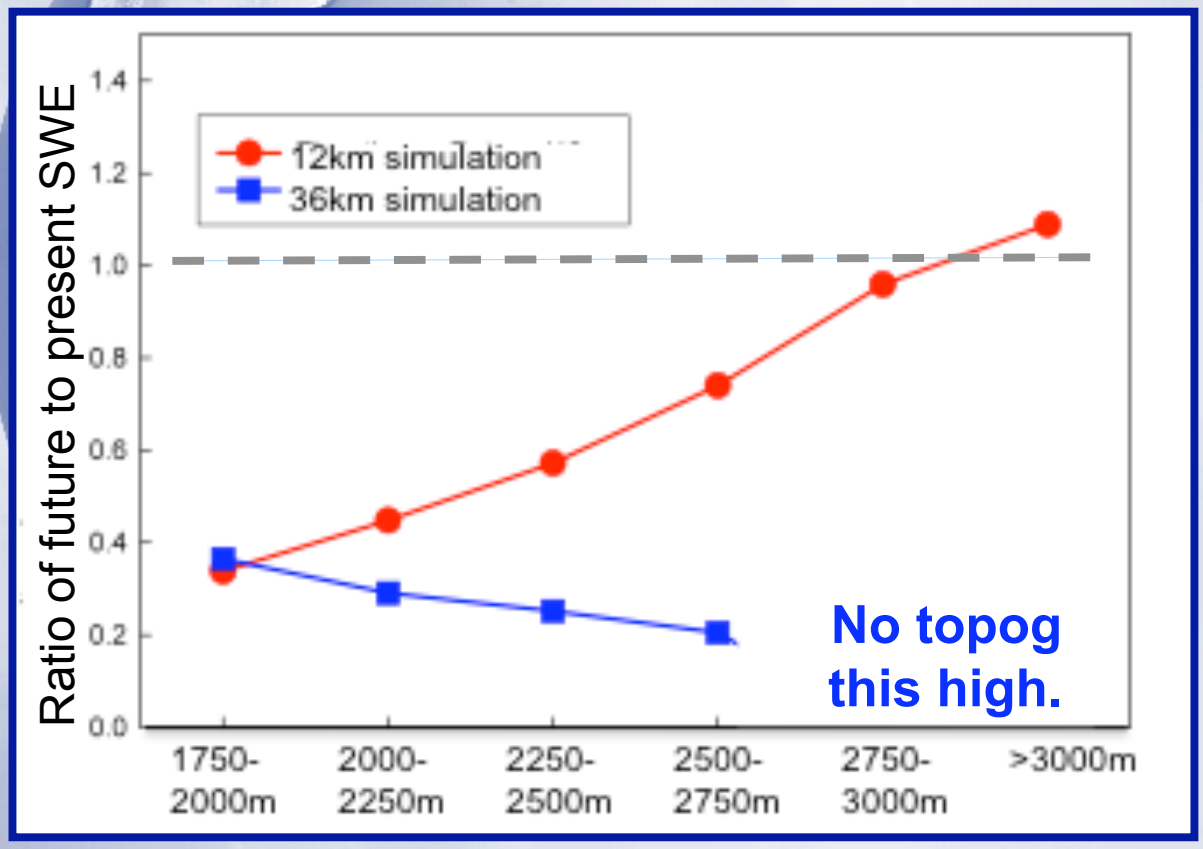
HIGH ELEVATION

12km Resolution:
Snowpack loss is greater at lower elevations => likely due to greater snow-albedo feedback as snow is less in lower elevations

California Climate Change: Dynamical Downscaling

Impact of Model Resolution/Topography

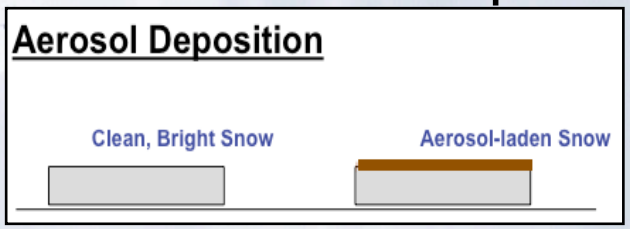




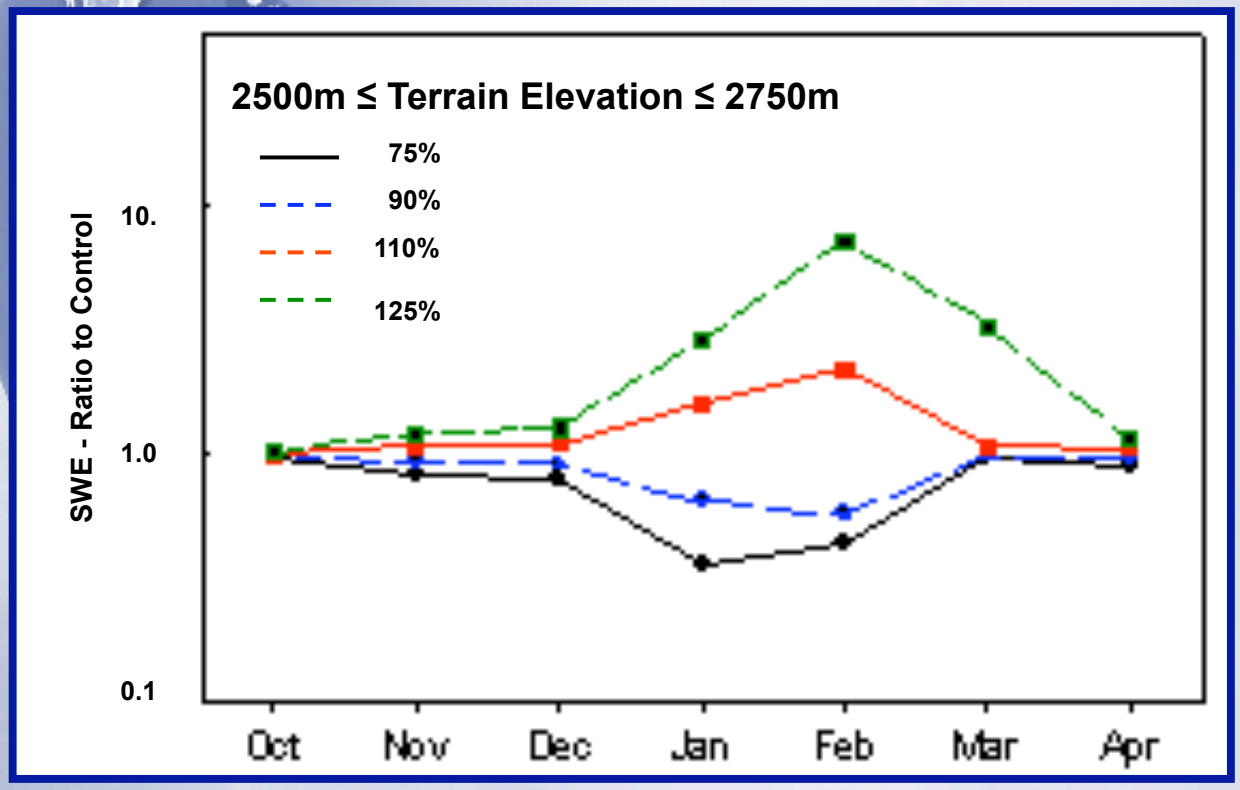
Assessements of SWE need to be derived from high -resolution model projections.

California Climate Change: Dynamical Downscaling

Impact of Snow Albedo/Aerosol Deposition: *Role of Emissions?*



SWE sensitivity to changes in snow albedo



California Climate Change: Dynamical Downscaling

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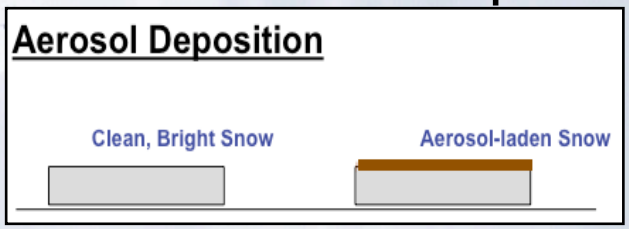

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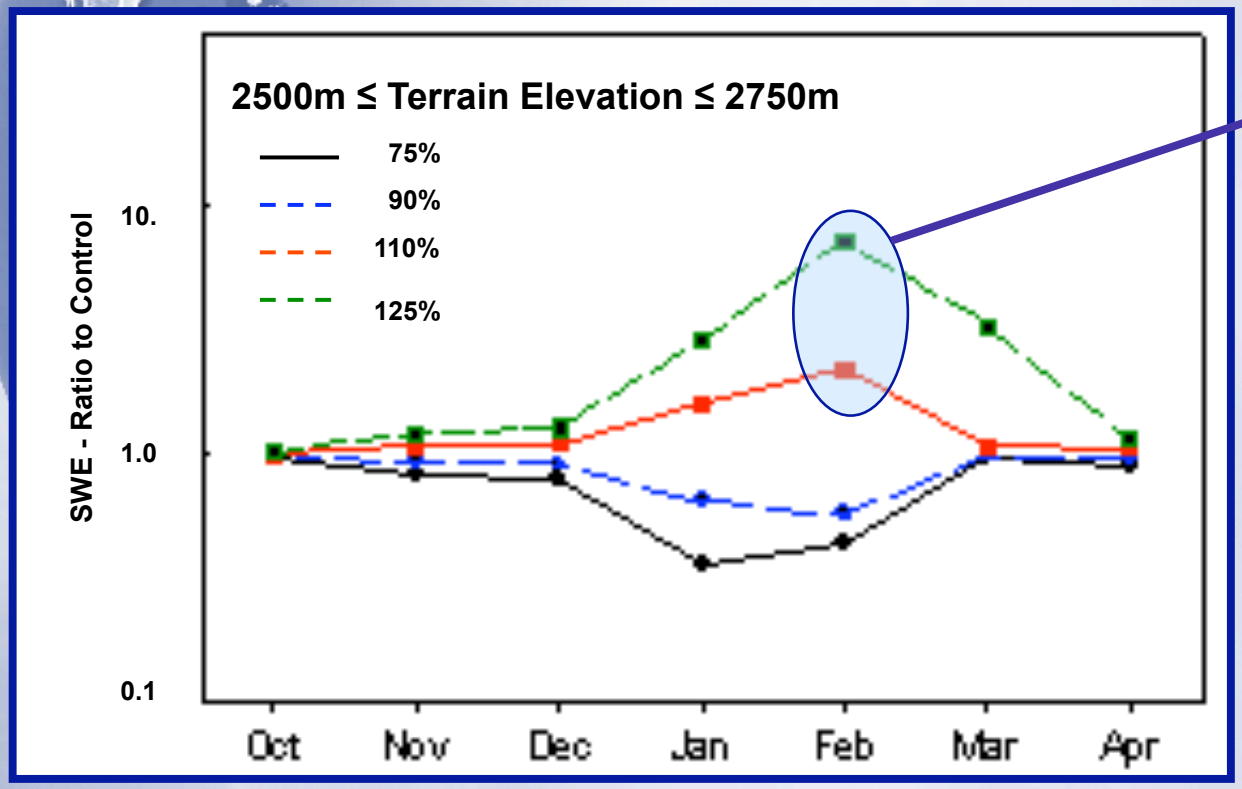

Modest increases in snow albedo lead to significant inceases in SWE later in season

California Climate Change: Dynamical Downscaling

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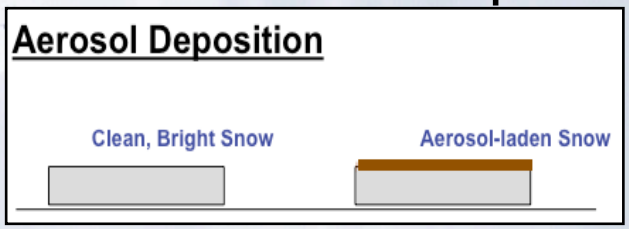

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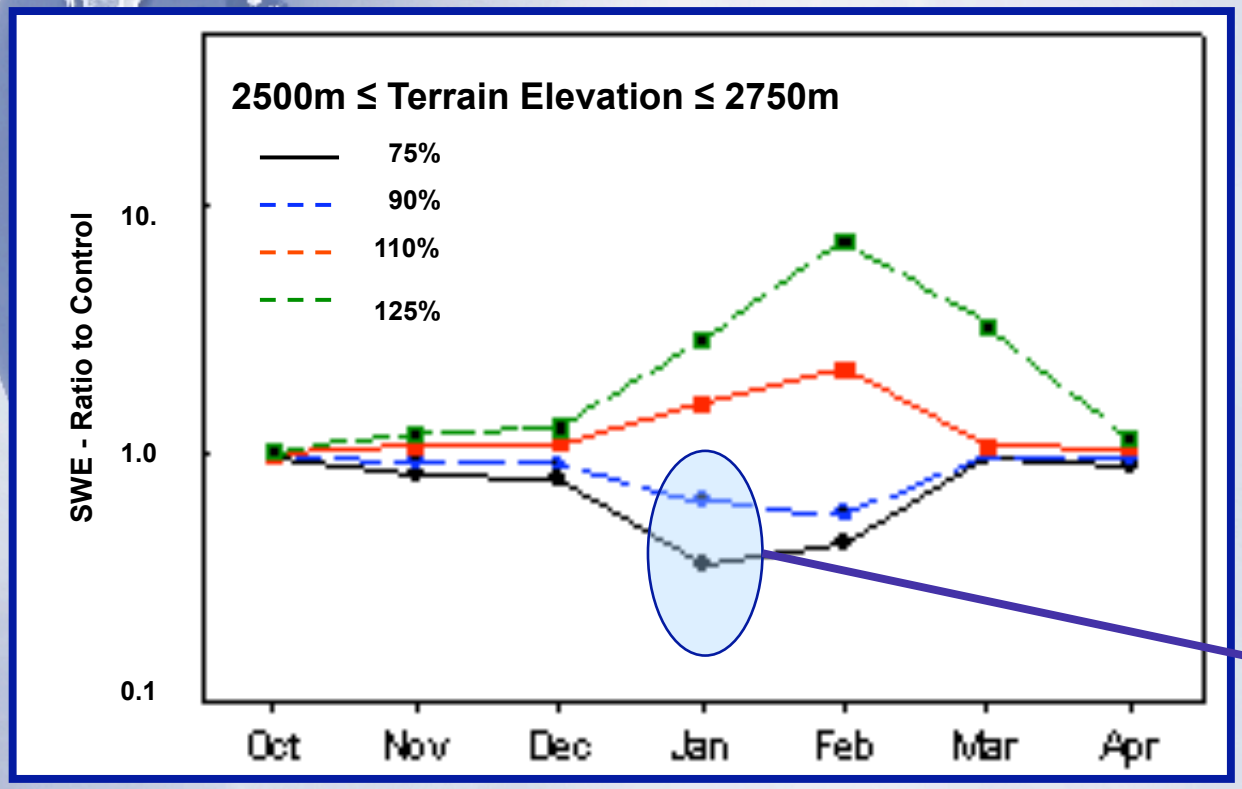

Modest decreases in snow albedo lead to significant decreases in SWE earlier in season

California Climate Change: Dynamical Downscaling

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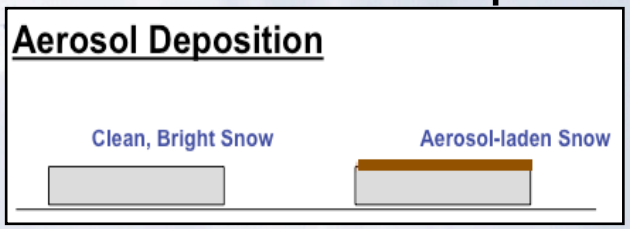
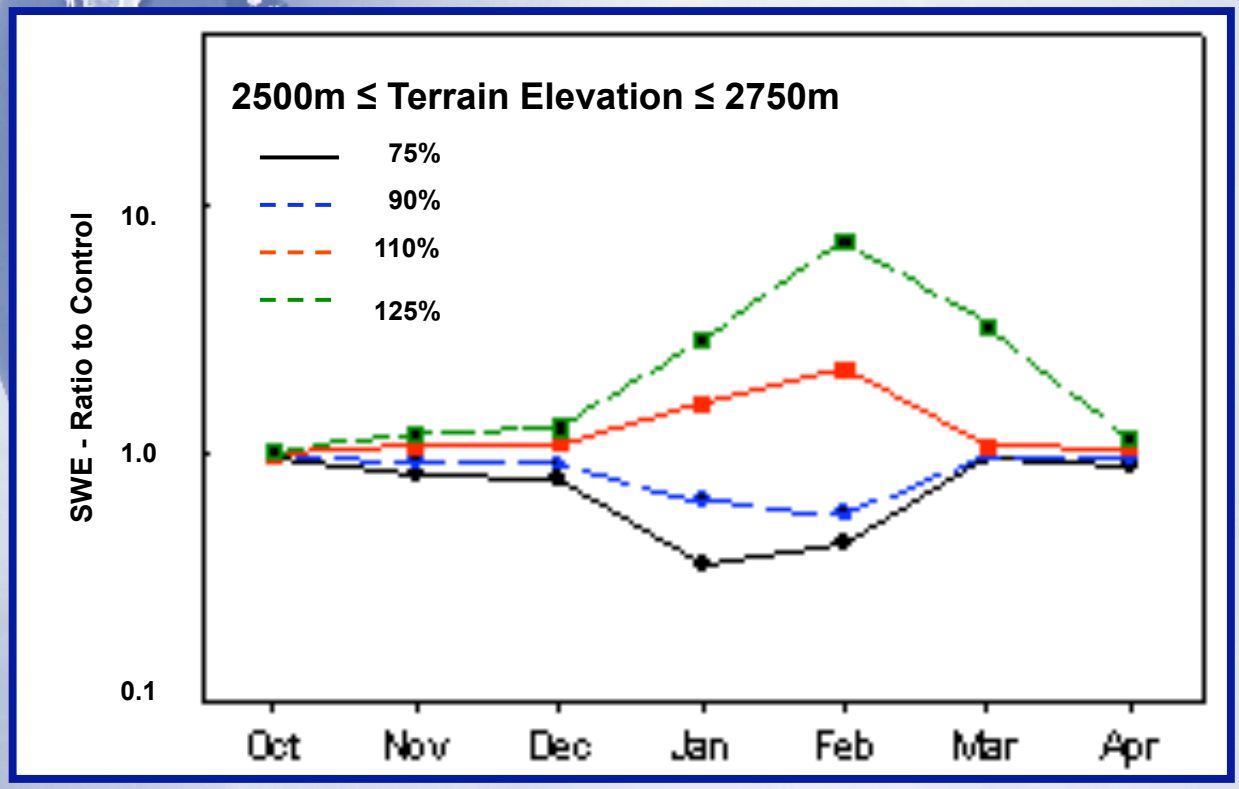


SWE sensitivity to changes in snow albedo



Small changes in snow albedo have dramatic changes on projected SWE.

Needs to be examined more thoroughly with respect to projected aerosol emission.

California Climate Change: Dynamical Downscaling

Single versus multi-layer snow model

Forcing

Sensitivity Simulation
NCEP/NCAR Reanalysis
1998

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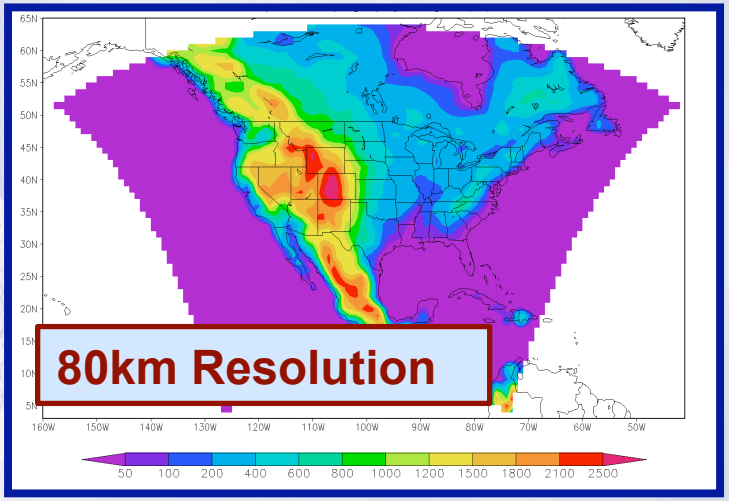

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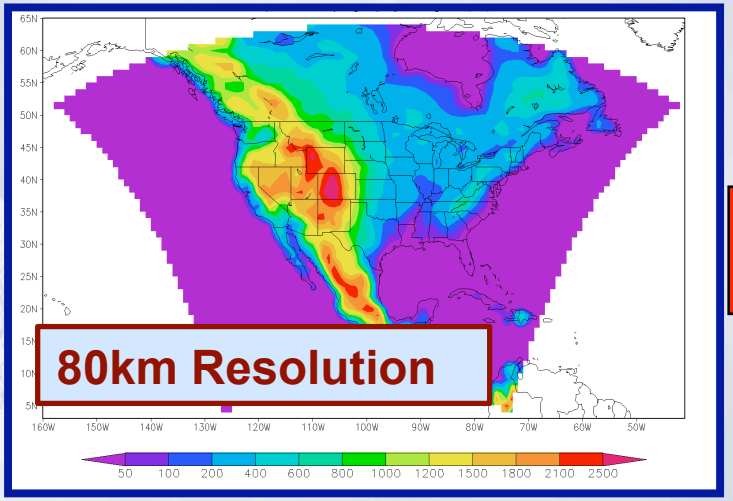
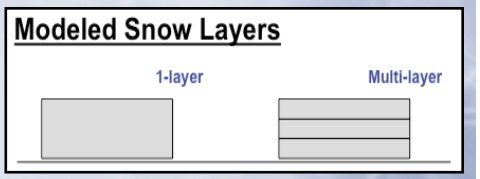
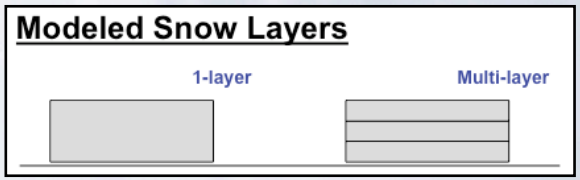


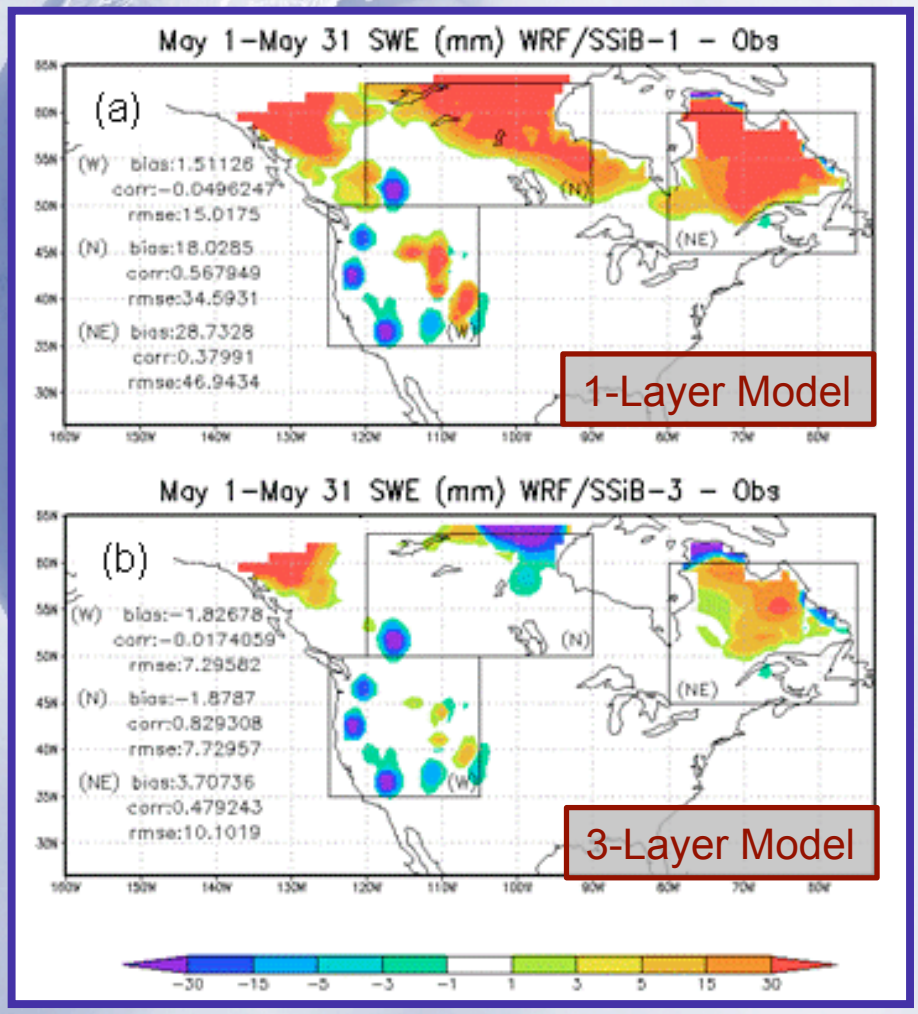
Results



California Climate Change: Dynamical Downscaling

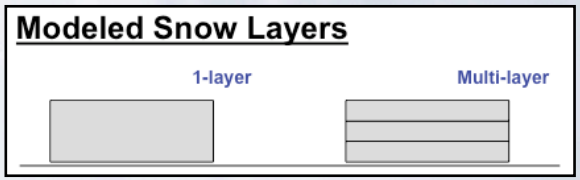
Impact of Snow Layer Physics Representation

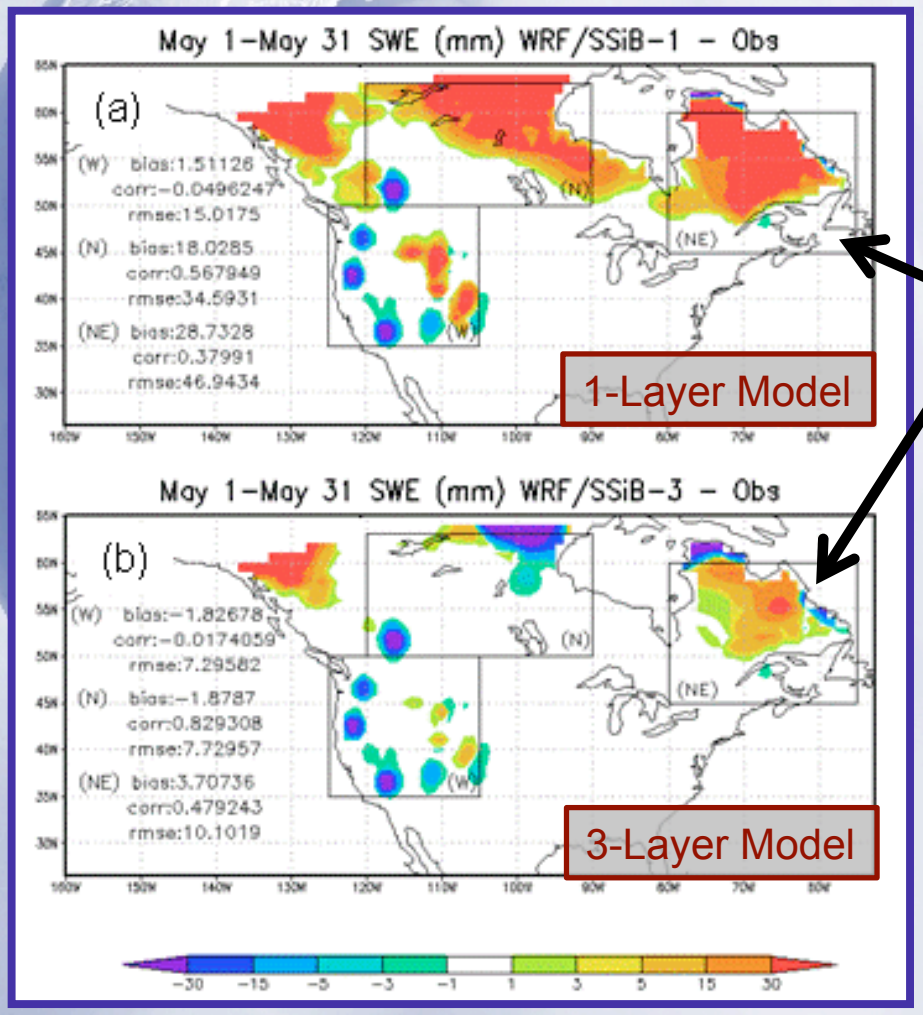




California Climate Change: Dynamical Downscaling

Impact of Snow Layer Physics Representation

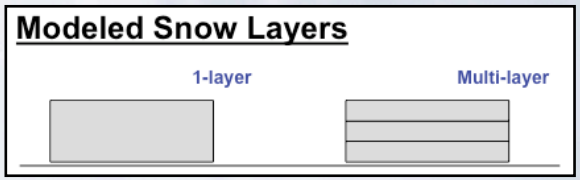


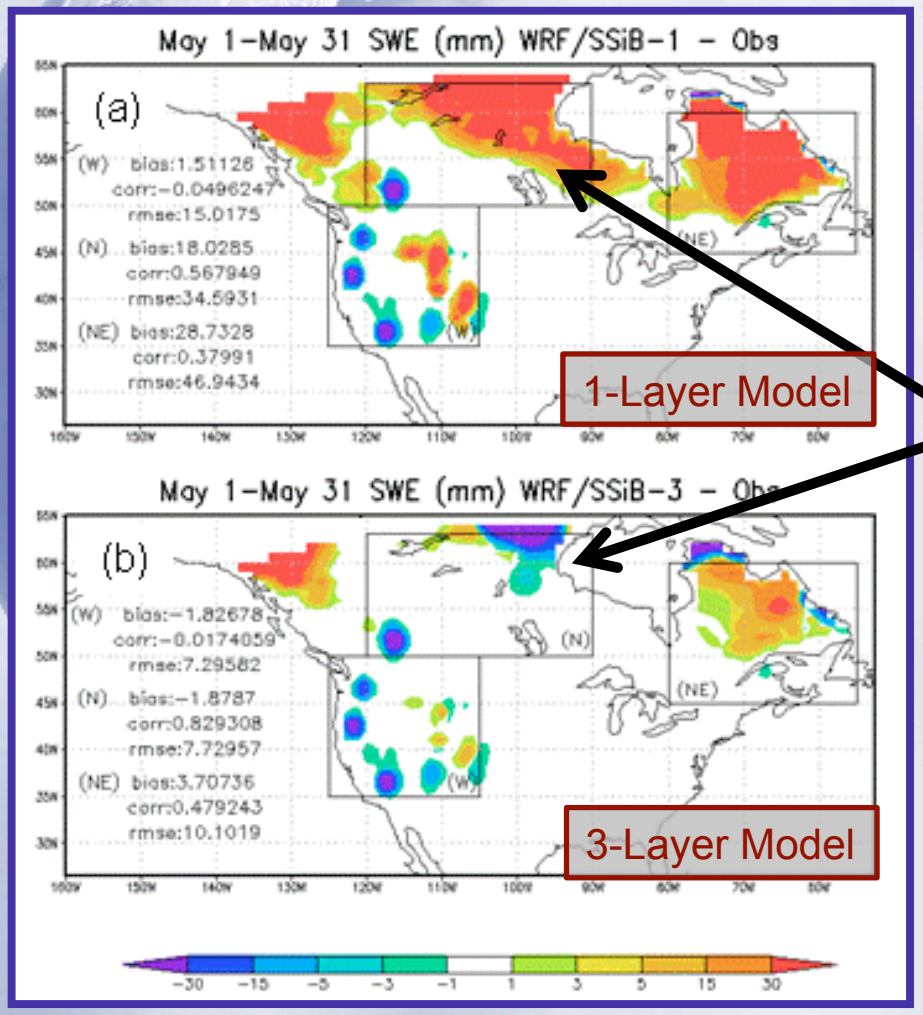


Significant Reductions in modeled SWE biases – typically an over estimate.

California Climate Change: Dynamical Downscaling

Impact of Snow Layer Physics Representation





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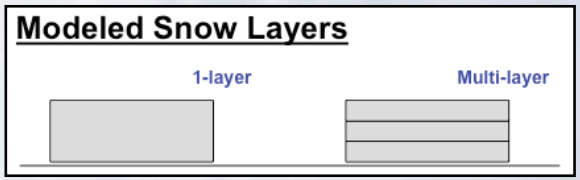
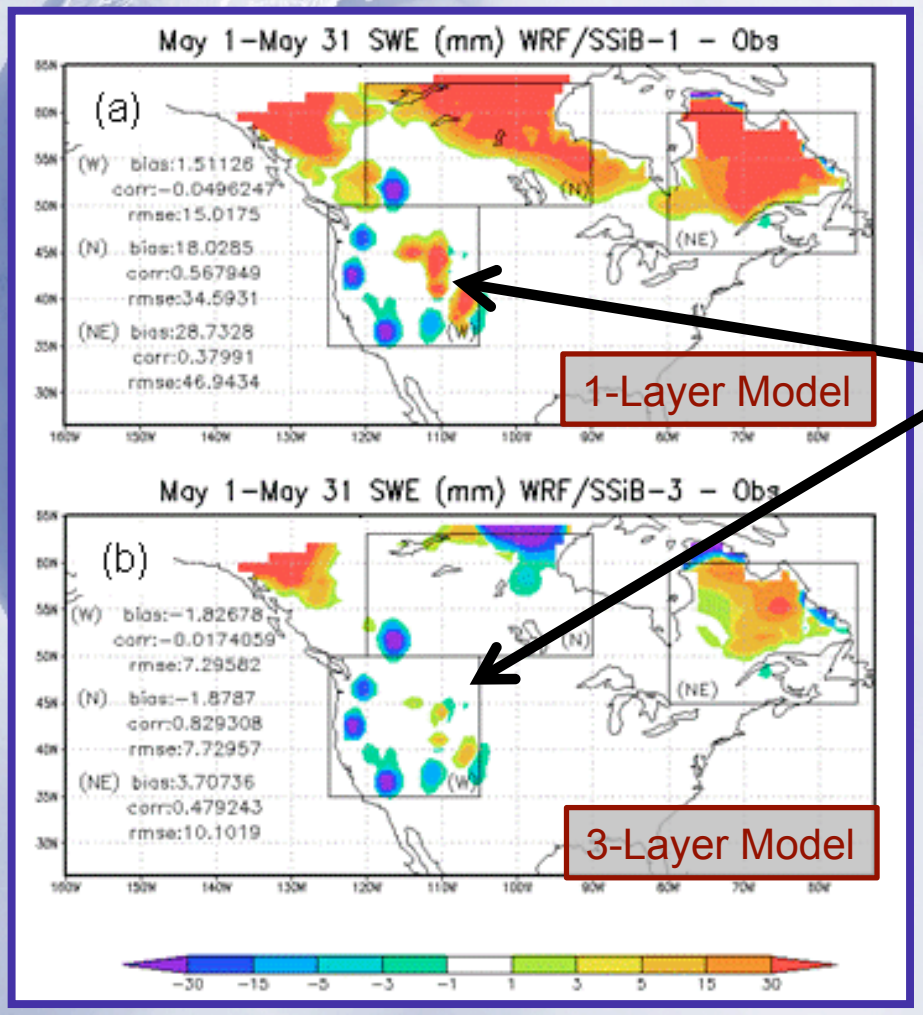
California Climate Change: Dynamical Downscaling

Impact of Snow Layer Physics Representation



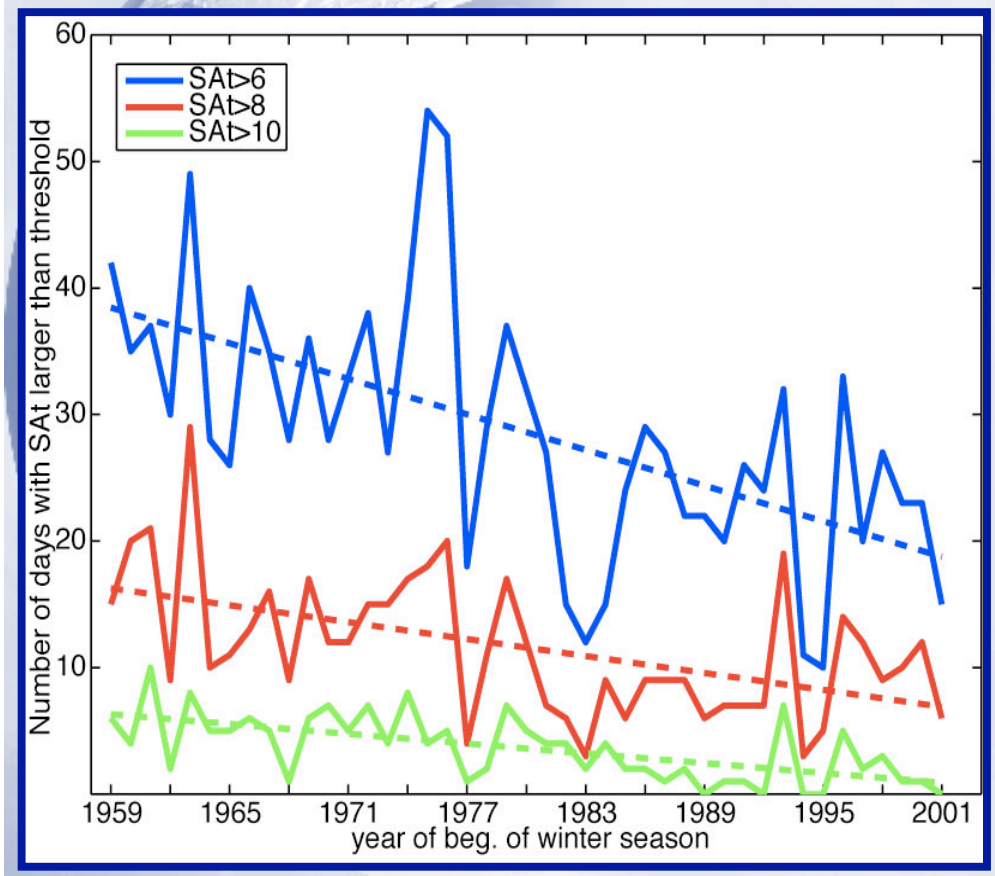


Significant Reductions in modeled SWE biases – typically an over estimate.

Less realistic single layer snow models may underestimate projected snowpack loss.

California Climate Change: Santa Ana Winds

Hughes et al. 2008



California Climate Change: Santa Ana Winds

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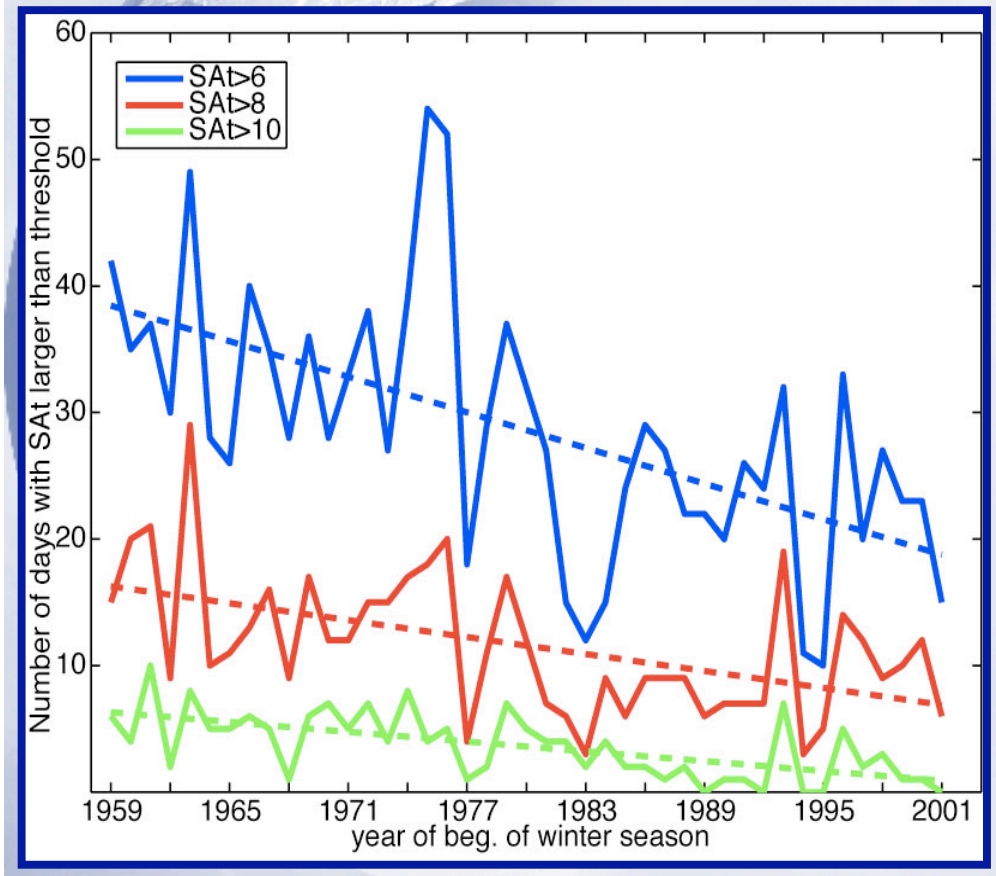

- Analysis of a regional climate hindcast'indicates Santa Ana wind conditions have decreased 30-50% from 1959 to 2001.
- Reduction arises from both large-scale synoptic forcing (strong offshore upper level winds) and local katabatic forcing (cold desert air pouring through the gaps).
- The climate change dynamic downscaling experiment suggests further decreases in the future (~2050).

Summary

- An trend in earlier Sierra snowmelt timing is present in monthly SWE observations - attributed to the sensitivity of peak snow mass date to local March temperature.
- Regional dynamic downscaling experiments have been performed based on NCAR CCSM SRESA1B suggesting considerable changes to CA hydroclimate by 2050.
- There is considerable model sensitivity of CA snowmelt and snowpack loss to model resolution, snow albedo treatment, and model snow layer formulation.
- Santa Ana winds are less frequent under climate warming conditions because the continental interior warms more than ocean, altering large-scale and local pressure gradients.
- *Caveat: Some results based on only one GCM projection & one RESM formulation.*

Future Work

- Regional model validation with ground-based and satellite observations where possible : synoptic fields (e.g., temperature, clouds, winds), hydroclimate (e.g. snowcover, albedo), air quality.
- Continue work on improving snow physics, e.g., multi-layer formulation, snow spectral albedo parameterization based on snow grain size and black carbon/dust contamination.
- Compare observational dataset of peak snow mass date to regional model output both for validation purposes and for understanding mechanisms for the changes.
- Santa Ana Winds: 1) Validate analysis against ground-based observations, and 2) Identify how other critical fire weather parameters (e.g., relative humidity) have changed.
- Investigation of the impact of anthropogenic climate change on the air quality in California.